PROCEEDINGS

OF THE

INTERNATIONAL ENGINEERING CONGRESS,

DIVISION OF MARINE AND NAVAL ENGINEERING AND NAVAL ARCHITECTURE.

HELD IN CONNECTION WITH THE WORLD'S COLUMBIAN EXPOSITION AT CHICAGO, JULY 31—AUGUST 5, 1893.

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IN TWO VOLUMES.

VOL. II.

PAPERS XXVI–XLV.

FIRST EDITION.

FIRST THOUSAND.

NEW YORK:

JOHN WILEY & SONS,

53 EAST TENTH STREET.

1894.

ROBERT DRUMMOND, ELECTROTYPER AND PRINTER, NEW YORK.

LIST OF PAPERS IN VOL. II.

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XXVI.

TUBULOUS OR COIL BOILERS.

By CHARLES WARD, Esq.,

Proprietor and Manufacturer of Ward's Tubulous Boiler; Builder of the Tubulous Boilers on U. S. S. "Monterey."

We understand the term tubulous or coil boilers to apply to that class of boilers constructed of small or moderate-sized tubes connected under varying combinations, in which the water contained is in the tube, and the heat is applied to the exterior.

As this is a Congress of Marine Engineers, it is our purpose to consider only the particular style of boiler as adapted for marine purposes, or, in other words, Marine Water-tube Boilers.

Water-tube boilers have become an established success for stationary purposes, and the question naturally suggests itself, Why not equally so for marine purposes? This question is much more easily asked than answered. There are so many varying and ever-new conditions, that a steam-boiler is by no means an amphibious creature. It must be either aquatic or terrestrial. The requirements are so different that it must be suited to the atmosphere in which it breathes, moves, and operates.

The ever-growing tendency of the present age is nowhere more aggressive than in marine engineering. Conditions which were considered all that were desired a few short years ago are now utterly unsatisfactory. The low pressure of steam used gave way to moderate increase, and this to greater tension: first we had low-pressure engines; then low-pressure condensing; then compound, compound-condensing, triple-compound, and now quadruple-expansion engines. So that

to-day we find the steam-pressure used for the propulsion of vessels increased from that of little more than the atmosphere to hundreds of pounds per square inch—a not unusual requirement being 250 pounds.

This increase of steam-pressure has only kept pace with the continually increasing requirements of greater tonnage and greater speed, which call for immensely more power; so that the modern transatlantic liner is like a small continent moving across the vast waters with the precision and regularity of a heavenly body moving through space—veritable meteors on the great waters!

To furnish the steam-power to move these ponderous structures through the water at these marvellous speeds has called forth the greatest engineering ability of modern times. Vessels wonderfully constructed, of leviathan proportions, of enormous carrying capacity and great speed, demanding powers and appliances which only a very few years ago would have been considered entirely impracticable, are now recognized facts, of which the "Campania" is a magnificent illustration.

While these splendid results have been attained, it is generally admitted in engineering circles that we have reached the apex with present boilers, so that for still greater powers and speeds we have to look for other designs. So fully is this conceded, that it was thought worthy the attention of this Congress to discuss the coming competitor of the present marine boiler under the subject of my paper—Tubulous Boilers.

The demand for greater speeds means less weight and greater efficiency, with less space occupied. To meet this demand the Scotch boiler has been pushed to the utmost, and the effort to obtain greater duty by forced draught has brought about a series of disastrous results. Although in the merchant marine, where more space and weight may be devoted to a given power, these difficulties have not been so serious, in vessels of war they have grown to such dimensions as to call for a halt. The means once sufficient are fast becoming obsolete. Steam-boilers that were A1 at Lloyd's fail to meet the progressive requirements.

Engines may be compounded by adding another cylinder

above the present one, or the existing compound may be made triple by the same method, or even quadruple; but insufficient boilers must be made new. To make new ones suitable to the more exacting conditions, they must be made of superior material and of small diameter, giving greater strength, and preserving an elasticity which seems antagonistic to the first requisite. This new creature must do much more than its predecessor, and in less time; so that it becomes a creature of nerves, inhalation, and respiration, with a throbbing pulse, the rate of which is heightened by the rapid consumption of modern forced draught.

This condition of combustion has worked such grievous ills, that it has been called "a creature of the devil." Certainly no modern method has caused more evil among naval boilers than this creature, wherever he may have originated.

The troubles resulting from forcing naval boilers have been so serious as to cause apprehension and consternation at the English Admiralty. So persistently have these troubles prevailed on the trials of modern English war ships, that scarcely a naval boiler worked under strong forced draught has come from the trial unscathed. Stay-bolts strained, crown-sheets or combustion-chambers deformed, tube-plates distorted, and tubes leaking to such a degree that trial-trips have been postponed or abandoned, and horse-power and speed requirements modified.

Reduction of air-pressure (and consequently diminished duty) and ferrule devices have to some extent modified these results, but time will show how satisfactory these devices may prove.

It is a source of great satisfaction that in our new navy these unpleasant results have not seriously appeared, but there is sufficient indication that growing requirements call for something better. The present boiler, with all its achievements—and they are great—has arrived at that stage when greater results appear obstructed by insurmountable obstacles.

These obstacles suggest that the new design must be of the lightest construction consistent with permanence and the maintenance of a working pressure in excess of *present demands*, capable of the highest efficiency to be obtained with security under the most trying rate of combustion and long-

continued runs under average conditions; and while filling these requirements, it must occupy the smallest possible space. It should be of the utmost simplicity, easily stowed, of interchangeable parts of such dimensions as to admit of being installed in the vessel after the ship is completed, and of easy access for cleaning, examination, and repairs. These considerations have been apparent, and aimed at by engineers and inventors for many years past.

We cannot within the scope of this paper give more than a passing history of the development of Water-tube Marine Boilers, and will briefly notice such as have played the most important part and have survived the ordeal of new ideas. The most active periods in the history of this development seem to have been from the year 1876 to the present time. During the early part of this period many of the present representatives were busily at work with more or less success.

Among the earliest may be mentioned Mr. Loftus Perkins, one of the early heroes of high-pressure steam and numerous expansions. Early in 1879 he fitted the "Wanderer" with water-tube boilers and multiple-expansion engines, placing in the vessel four tubulous boilers having a total of 3040 sq. ft. of heating-surface and 76 sq. ft. of grate, to work under a steam-pressure of 400 lbs., resulting in a development of 907 H.P., the engines being 17, 34, and 48 inches diameters of cylinders, and 30 inches stroke. This is doubtless the first time water-tube marine boilers were used in battery. Unfortunately, Mr. Perkins' efforts were not crowned with as much success as his energy and forethought deserved, for he was unquestionably one of those men who are ahead of the times in ideas and principles, though he was not able to perfect them. A more satisfactory result was afterward obtained with the steamer "Anthracite," which was doubtless a forerunner of better things to come. This little steamer crossed the Atlantic in evidence of practicability.

About the same time that Mr. Perkins was laboring in London, Mr. Herreshoff was, with wonderful energy and skill under physical disadvantages, perfecting his coil boiler, his first patent dating 1877. From that time to the present this gentleman has wrought many changes in his coil, from the single to the double, to which he has added the coil feed-water heater and superheater, until, at recent dates, after

having aroused the engineering world with his wonderful coil generator, he abandons it in favor of one of the box sectional design. Now we see mention of his improved Thornycroft.

Almost simultaneously with Mr. Herreshoff, the writer was engaged in the tubulous-boiler evolution, his first effort being for a light-draught river steamer, which the owner was anxious should run on the Irishman's early dew. This was in 1877 and 1878. In 1880 we built our second boiler for 200 lbs. of steam. This boiler has 32 sq. ft. of grate and 700 sq. ft. of heating-surface. We say "this boiler," because it is still in active service on a Western river tow-boat owned by the Engineer Corps of the U. S. War Department. It is now furnishing steam for two engines 12½ in. diameter, 4 ft. stroke, making 30 revolutions with 180 lbs. of steam, cutting off at three-quarters. This boiler, in constant use these fourteen years, has during this period lost only two tubes, and has not cost over one hundred dollars for actual repairs.

In 1882 the writer built perhaps the largest water-tube marine boiler up to date—certainly for the highest steam-pressure. This boiler was for the American Quick Transit SS. Co., who at that time dreamed of a five-day ship. It had 3000 sq. ft. of heating-surface, 85 sq. ft. of grate, weighed fifteen tons without water, was built for 500 lbs. steam-pressure, and tested in the boat to 900 lbs. hydraulic pressure. (See Plate I.) The original compound engines were a failure, and at this juncture the writer prepared a paper setting forth the claims of high-pressure steam, and urging the adoption of 200 or 250 lbs. pressure and a triple-expansion engine. This paper was read before the steamship company's representatives, and Mr. W. H. Rodman, their consulting engineer, approved and indorsed the recommendation. A contract was made with the Bath Iron Works, and the first triple-expansion engine built in America, designed by Mr. C. H. Hyde, was placed in this vessel. Particulars of this boiler and engine may be found in *Engineering* of Aug. 21, 1885. The vessel fitted with this boiler was formerly the "Meteor," of Bliven fame, now called the "Golden Rod," and owned by Commodore Archibald Watt of New York, and is among the finest yachts of to-day.

In 1883 Mr. Thornycroft of London seems to have entered the field by designing a tubulous boiler for a small steam-

launch he was building for missionary service on the Congo. This boiler was entirely unlike the present famous boiler bearing his name, and is shown in Plate II. We do not find any particulars of the size or heating-surface of this boiler, but it worked satisfactorily, and furnished steam for two non-condensing engines $6\frac{1}{4} \times 8$, making 480 revolutions per minute. We mention this to show Mr. Thornycroft's early work.

About the same time as the early efforts of Herreshoff, Perkins, Ward, and Thornycroft were those of Mr Belleville of France. In 1879 he installed his first marine tubulous boilers of 1000 H.P. in a French naval vessel. These seem to have been so satisfactory to the requirements of the time that nearly 100 steamers were fitted with these boilers between the years 1879 and 1890, ranging in power from 10 H.P. to 14,000 H.P.

In 1884 the Ward launch boiler was developed.

In 1887 Mr. E. E. Roberts patented his pipe boiler, which has met considerable success in small and medium sizes.

In the same year (1887) Mr. Thornycroft patented in England, and in the following year in the United States, his famous boiler, installed with such excellent results on a second-class torpedo-boat early in 1886, and afterwards on the "Ariete" and "Rayo," which were delivered to the Spanish Government in 1889.

In 1888 Mr. Wm. Cowles secured patents on a tubulous boiler, which has been introduced on fire-boats, and tested in competition by the U. S. Government.

In 1889 the patents of the Nathan P. Towne and the Amasa Worthington water-tube boilers appeared simultaneously. They are much alike, the difference being more in construction than in principle.

The year 1890 produced an adaptation or variation of the Thornycroft in the shape of Mr. Charles D. Mosher's patent, used for the first and, at present, only time on the racing boat "Norwood," owned by Mr. Norman Munro.*

The year 1891 develops Normand's tubulous boiler—an outgrowth of Thornycroft's—by its installation on Torpedo-boat No. 149 of the French Navy; and also Mr. Yarrow's tubulous boiler, which was applied to a second-class torpedo-boat,

* I have since learned that Mr. Mosher has built eleven of his boilers.—C. W.

resulting in an increase of speed of one mile over a similar boat fitted with locomotive boilers.

In 1892 Ward develops his new navy or torpedo-boat water-tube boiler. It is built on the same general lines as the Ward sectional marine boiler, the sections being made horizontal instead of vertical, and so arranged as to be drawn out into the fire-room for repair.

Such is a brief record of the progress and development of such tubulous boilers as have played a conspicuous part in the progress of this branch of marine engineering.

We now propose to describe briefly the several boilers mentioned.

THE HERRESHOFF COIL BOILER.

(Plate II.)

stands alone a representative of what we may term a "geyser type." Its exterior is a vertical sheet-iron cylinder covered by a cone, the smoke-stack standing on its centre. The grate is round, and is surrounded by a fire-brick lining: on this lining the boiler proper is carried, which is formed of a continuous wrought-iron tube of varying diameters, the largest diameter being at the bottom. It is coiled spirally around and over the furnaces, the spaces between the tube coils being such as to cause the heated gases to pass around every coil. At a small distance outside of this and immediately inside the casing, another coil starts also from the fire-brick base, forming a close water-tube spiral lining to the casing, and from the casing a third coil, which is a continuation of the second, curves in a horizontal spiral towards the centre, leaving a circular opening the size of the base of the smoke-stack. The central opening of the interior coil of the boiler proper is closed by a deflecting-plate, so that the heated gases pass through the spaces of the interior coil to the space between the two annular coils, thence to the smoke-pipe. The feed is introduced at the bottom of the outer coil, which acts as a feed-water heater, delivering the hot water to the inner coil, or boiler proper, at the top, whence it takes a circuitous course to the bottom of the boiler, where it is delivered into a cylindrical separator in front of and outside the boiler. The amount of feed is so varied as to give dry steam from this

separator to the engine; the excess of water drained from the separator is used again. The boiler represented is 56 in. diameter, 65 in. high, has 174 sq. ft. of heating-surface and 12.5 sq. ft. of grate, and weighs 3562 lbs. or 20.4 lbs. per sq. ft. of heating-surface.

THE PERKINS BOILER

is rectangular in form, the base which surrounds the grate being a tube of similar form, with the corners rounded. A series of these tubes piled one above another and connected with 1″ nipples to each other, constitutes the fire-box. Above the fire-box are arranged 17 tubes side by side, 10 tubes high. These tubes are 3″ in external diameter and 4′ 7½″ long, closed at each end, and connected to each other vertically by 1″ screw-joint nipples. The steam made in these tubes is collected by a 6″ transverse tube, which is connected to each vertical pile by 1″ right and left hand screw nipples, forming an equivalent to a steam-dome, from which the engine is supplied. The construction of the boiler must have been a work of great patience. Each of the four boilers of the "Wanderer" had 760 sq. ft. of heating-surface and 19 sq. ft. of grate; ratio of grate to heating-surface 1 to 26.8, with a weight per square foot of heating-surface of 25 lbs.

WARD'S MARINE BOILER.

(Plates IV., V., VI., VII.)

Its exterior form or casing may be described as a vertical cylinder, with an enlarged base forming the fire-box. Above the casing is a cone surmounted by a smaller cylinder, covered by another smaller cone which carries the smoke-stack.

It is composed essentially of a central vertical drum and a number of concentric cylindrical piles of inclined tubes annularly arranged around the drum and above the fire; each pile or coil being carried in its proper position by two water-legs, which are the means of circulation by being connected to a horizontal manifold at the top and bottom at opposite sides, which in turn is connected with the drum. On the opposite side at the bottom there is a third horizontal manifold, forming a base to receive the forward leg of the coils; a blow-off valve from this manifold acts as a surface blow for the tubes. The operation is as follows:

The feed-water being introduced at *H*, or any convenient point, is conducted by an internal pipe (having an inverted "rose," *A*, on its end) to the centre of main cylinder *B*, where, in its slow descent in small jets, it becomes heated by contact with the surrounding water, and at once precipitates the mud into the bottom of the drum *L* before entering the tubes.

The generator being filled to the proper water-line and fire introduced, it is evident that the heat developed is rapidly absorbed by the water in the tubes *G*, which, becoming rarefied and expanded at once, pours over through manifold *I* into the central cylinder *B*, causing an active circulation to and from the same through the lower horizontal manifold *C*, vertical manifolds *E E E*, generating-tubes *G*, and upper manifold *I*.

This forms a continuous circulation of the water, the rapidity of which is accelerated by the development of heat and the increased demand for steam, thus making the heating-surface more active in proportion as the fires are forced, and the demand for steam increased, which not only facilitates increased generation of steam, but secures dry steam by presenting an ever-changing current of water laden with heat, ready to form steam on reaching the central cylinder.

The heavier remaining water descends again to make the circuit. Any tendency of the water to follow the steam to the steam-pipe *J* is prevented by a perforated diaphragm introduced in the centre cylinder *B*, just above the upper horizontal manifold *I*, causing the steam to rise through numerous small holes over the area of the cylinder.

To avoid the disastrous result of unequal expansion and contraction, every individual piece is free to expand and contract independent of any other.

By removing the cover of the smoke-box and the upper manifold *I*, any of the piles of circles may be *raised* out of the jacket for examination or repairs, and replaced in a short space of time.

The half-circles or tubes are connected to vertical steel manifolds by right- and left-hand steel bushings, which may be easily renewed. (See small cut, on upper right-hand side.)

The cleaning of these boilers is accomplished by first blowing off the mud through the valve *M*, and afterwards flushing the tubes by opening the mud-valve *O*, which draws

the clean water through the manifold *C*, vertical manifolds *E E E*, tubes *G*, down through the vertical manifolds *N N N*, horizontal manifold *P*, and mud-valve *O*, thus perfectly cleaning the tubes should any dirt remain in them.

These generators work the muddiest of river waters.

Annexed is a cut of a six-coil Ward boiler, which explains itself. Also, drawings of the Ward boilers as fitted to the U. S. coast-defence vessel "Monterey."

THE THORNYCROFT BOILER

(Plate VIII.)

is entirely different in form from those previously described, as may be seen by the annexed cuts, which are to a great extent self-explanatory. The elements are three horizontal drums or cylinders arranged parallel with each other, one on either side of the grate and a larger one immediately over the centre line of grate and some feet above, in triangular form. The central horizontal drum above is connected to the two side drums by large circulating downcast tubes in the front of the boiler and outside the casing. The heating-surface is obtained by numerous bent tubes starting from the upper surface of the side cylinders, coming together immediately under the central horizontal drum in arch form, and then returning upwards and around this drum enter it on the upper side of the centre on each side, respectively. The inside and outside tubes running fore and aft are interlapped, forming a tube wall or partition, open only at the lower and upper ends, so that the products of combustion pass through these openings from the furnace-chamber up through the nest of tubes to the smoke-pipe, thus protecting the horizontal and central drums from intense heat. The water-line being one third up the central horizontal cylinder, the circulation is obviously through this drum, down the large circulating-tubes into the side cylinders, and thence up through the generating-tubes to the central drum. A system of deflecting-plates throws the entrained water to the water-space. The upper third of the tube surface appears to be superheating.

WARD'S LAUNCH BOILER,

(Plate IX.)

cylindrical in form, may be likened to a bird-cage. The bottom is the grate-area and ash-pan, surmounted by a base ring,

from which spring many tubes in one or more circular rows. These tubes discharge into a central drum in two or more radial rows. This drum is elongated sufficiently to furnish steam and water space, and the bottom is an inverted cone, from which are pendent numerous drop-tubes projecting into the combustion-chamber. These drop-tubes have an internal tube, which delivers the water at the lowest point, and a shorter tube, which permits the steam to escape from the highest point without obstructing the ingress of the water to the first-named tube. Feed is introduced to an annular cone, so that the circulation is down part of the tubes and up the others, depositing foreign matter in the base ring, from which it may be blown out.

THE ROBERTS PIPE-BOILER

(Plate X.)

is of the box-radiator type, rectangular in form, with a rectangular-shaped base, having deposit pockets at each corner; down each side perpendicular pipes connect a series of pipe-coils, which pass and repass many times over the fire and then discharge into a steam-drum, which is carried above the generative system by pipes from each end of the drum connected to the base. Steam is taken from the drum through a nest of pipes on either side, which act as drying or superheating tubes, from which steam is supplied to the engine on each side.

A system of feed-water-heater coils extends down on the outside of the generating-coils.

THE COWLES BOILER

(Plate XI.)

is similar in principle to the Thornycroft, with a different disposition of the tubes, which is so clear from the cut that further description is unnecessary.

THE TOWNE BOILER

(Plate XII.)

is a rectangular water-cased, water-tube boiler of box form, with tubes disposed from one side to the other diagonally across each other, with a horizontal central drum extending from front to back. The upper steam-space of the rectangular

water-casing is connected to this drum by a number of parallel tubes, which deliver the products of the generating diagonal tubes into the central drum, from which the entrained water is returned by rear circulating-tubes to the water-space of the rectangular casing. Feed-water coils and drying-tubes are run on the upper part of the boiler and over the drum. Screw-plugs in the water casing admit of the tubes being expanded or removed.

The engraving is so good as to need little explanation.

THE MOSHER BOILER *

is also, in general construction, like the Thornycroft, except that the tubes are bent towards the outside instead of towards the centre, and two steam-drums are used instead of one.

THE WORTHINGTON BOILER,

for which a patent was issued on the same day as that for the Towne, is a striking instance of two minds moving in the same direction at or about the same time. The two boilers are very similar in conception, though the results have been arrived at by different methods. In the Worthington, the tubes are assembled and connected to a series of cast manifolds which form the sides of the boiler, and the connecting and circulating medium between the lower and upper drums.

In the Towne, the crossed diagonal generating-tubes derive the supply from and deliver their products into the rectangular water-box casing at reverse sides and levels.

The plan of the generating-tubes and the relative position of the drum in each case are, as before stated, strikingly similar, as will be seen from the annexed cuts.

It is, however, only justice to say that although both patents were dated the same day, the record shows that the Worthington was filed more than four months earlier than the Towne.

THE BELLEVILLE BOILER

(Plate XIII.)

is also rectangular in form, is composed of several sections of zigzag—from front to back—generating-tubes carried above a fire-brick combustion-chamber. These sections or elements

* For illustration, see Mr. Mosher's discussion.—Editor.

take their supply from a box-shaped horizontal manifold running full length of the face of the boiler above the fire-doors. There are eight of these sections, each composed of 16 (3″.9 O. D.) tubes connected by return bends, the forward ends of which have hand-holes and covers. The upper ends of these elements deliver into the horizontal steam-drum above, which is divided into three compartments. At the left and at the bottom is a precipitator or sediment chamber. For a full detailed description of the working and results obtained from this boiler you are referred to an article by Mr. Isherwood in *Journal of American Society of Naval Engineers.*

THE NEW HERRESHOFF BOILER,

(Plate XIV,)

which is illustrated in its generative system, is somewhat like the Belleville without the precipitator and separating system. The cut shows its construction so clearly as not to need explanation.

THE YARROW TUBULOUS BOILER,

(Plate XV,)

is of the same general type as the Thornycroft. It has the three drums and circulating-tubes, the main difference being that the tubes are straight; the lower drums are flat on the upper surface, and each drum is divided in half, and fitted together by machine-bolts. A point that Mr. Yarrow claims as important is that the boiler, as a whole, may be galvanized.

THE NORMAND TUBULOUS BOILER,

(Plate XVI,)

is likewise of the same general class as the Thornycroft, Cowles, Mosher, and Yarrow, having the three parallel drums, one on either side of the grate, and one above for steam and water space, with the downcast circulating-tubes as in those named, the main difference being that the cylinder which forms the steam and water space is fitted with a steam-dome, which is inclosed in the smoke-duct, and thereby becomes superheating-surface. The tubes are for the most part straight, except where they are bent at the ends so as to enter the drum radially.

WARD'S NAVAL BOILER,

(Plate XVII.)

The last tubulous boiler we shall describe is Ward's latest design, which was specially prepared for torpedo-boats and torpedo-cruisers. It is especially adapted for vessels where the armor-plate comes close over the boilers. We have been pleased to call it the Royal Arch or naval boiler.

It is composed of three piles or sections of tubes arranged as concentric arches, forming a rectangular fire-box and combustion-chamber. Immediately under the arch is a horizontal drum ; at the rear and on top of the drum is a manifold, to which the top central manifold of each arch is connected. From the under side of the drum and at the rear is a downcast circulating connection which passes across to each side, connecting the lower leg of each arch section and making the circuit. Immediately over the combustion-chamber and under the horizontal drum is a nest or section of inclined tubes, forming, as it were, a crown sheet to the furnace; on top of this section is a dead-plate, which entirely prevents the intense heat from reaching the drum, and causes the gases of combustion to divide and pass up among the tubes on either side on their way to the smoke-stack.

It is obvious that on disconnecting any of the three arches they may be drawn out into the fire-room for repairs, etc. The photograph (Plate XVII), shows a boiler of this type having 2250 sq. ft. of heating-surface and 46½ sq. ft. of grate. It is 9′ wide, 10′ deep, 8′ 6″ high, and weighs ten pounds per per square foot of heating-surface.

The question now is as to the application and fitness of any, and which, of this great variety, and how far they are worthy of supplanting existing boilers.

There is no question that tubulous boilers fill a great want by their lightness. Several of the types mentioned can be furnished on a weight of 12 to 14 lbs. per sq. ft. of heating-surface. This is scarcely more than one-third the weight of the average Scotch boiler. Moreover, the most sanguine friends of the latter would not feel justified in depending upon one for over 180 lbs. steam, while there is no difficulty in furnishing tubulous boilers for 500 lbs. if desired.

In the matter of endurance under forced conditions, there is now no doubt, as many instances are on record where tubulous boilers have withstood the most severe firing, with rates of combustion up to 66 lbs. per sq. ft. of grate and upwards; in fact, we believe there is no difficulty in constructing a water-tube boiler which will stand up under an evaporation of 12 to 14 lbs. per square foot of heating-surface.

We do not, however, look for the greatest good from this point. We hope to see, as a result of water-tube marine boilers, enough boilers put on vessels to furnish steam for the power required, with little or no forcing for all ordinary work.

That tubulous boilers are the coming ones is daily more apparent. Only recently, as the result of competitive tests, has one of our war ships been fitted with this class of boiler, with most satisfactory results. Few engineers now think of a torpedo-boat without tubulous boilers. Our most noted builders, leaders in speed, are falling into line with such experienced and capable men as Thornycroft, Yarrow, Herreshoff, and Normand,—Schichau alone adhering to the locomotive style.

The U. S. Navy Department, realizing the great advantage to be gained from the use of tubulous boilers in war vessels, and especially so for coast-defence vessels, decided, if suitable ones could be found, to adopt them in the U. S. coast-defence vessel "Monterey." And in order to secure the best, and to find out, under most severe conditions, their fitness for long-continued use under forced draught, it was decided to offer the award of the contract for tubulous boilers for the U. S. S. "Monterey" to the manufacturer who should show the best results under twenty-four hours' trial with 2 inches air-pressure, and at the same time meet the other requirements of the department. Some twenty inventors or manufacturers submitted drawings and specifications: from these some five or six were considered by the Navy Department worthy of test. The conditions were so severe that only two builders entered the competition,—William Cowles of New York, and Charles Ward of Charleston, W. Va.

While space prohibits the full account of these tests, the reports with all data are exceedingly full and valuable, and may be found in the annual report of G. W. Melville, Engineer-in-chief U. S. Navy, 1890, to which you are referred.

We, however, give an extract from the *Journal of the American Society of Naval Engineers* setting forth the salient points of the two tests as prepared by P. A. Engineer W. M. McFarland, U. S. Navy.

"*Monterey.*"—The greatest interest attaching to this vessel is the use of coil boilers for about three fourths of the power. It will be remembered that in August of 1888 an advertisement was issued by the Navy Department inviting manufacturers of coil boilers to submit plans and prices for boilers for 3600 I.H.P. for the "Monterey." This was subsequently changed to 4200 I.H.P. After considerable delay the competitive trials were ordered, only two makers having finally come forward to carry out the competition—Mr. Charles Ward and Mr. William Cowles.

Each boiler was given two trials, each lasting twelve hours under forced draught, with an air-pressure of 2 inches of water. The Ward boiler used the closed fire-room plan, and the Cowles the closed ash-pit. The complete report of the trials will be given in the annual report of the engineer-in-chief, but we are permitted to give the following abstract:

	Ward.	Cowles.
Date of tests	Dec. 18 and 19, 1889.	Apr. 28 and May 8, 1890.
Boilers tested:		
Grate-surface, square feet	53	47
Heating-surface, square feet	2,473.5	2,026.75
Weight of empty boiler without smoke-pipe, tons	11.84	9.75
Weight of same with water, tons	13.85	11.55
Ratio H. S. to G. S	46.67	43.12
Proposed Boilers:		
Number for the "Monterey"	4	6
G. S. of each	75	47
H. S. of each	2,988	1,998.5
Weight empty, tons	13.58	9.6
Weight with water, tons	15.86	12.65
Duration of test, hours	24	24.15
Fuel consumed, total, pounds	70,022	45,620
Refuse from fuel, total, pounds	3,389	6,327
Combustible consumed, pounds	66,633	39,293
Per cent of refuse	4.84	13.87
Total feed-water used, pounds	461,885	280,822
Temperature of feed-water	50.4	58

	Ward.	Cowles.
Steam-pressure, pounds	160	160
Air-pressure in inches of water	2	2
Coal per hour per square foot of G. S.	55.05	40.19
Combustible per hour per square foot of G. S.	52.4	34.62
Coal per hour per square foot of H. S.	1.18	0.932
Per cent of moisture in steam	{ 11.62 18.85	
Per cent of superheating		{ 7.5 3.8
Apparent evap'n from temp. of feed at temp. of steam, per lb. of coal	6.60	6.16
Same per pound of combustible	6.93	7.15
Potential evap'n (allowance being made for moisture or superheating), under above conditions per lb. of coal	6.00	6.50
Same per pound of combustible	6.30	7.54

These tests were made in the usual way for all evaporative tests, starting with steam raised and bare grates, and ending with no fire and steam not forming. This, of course, is the accurate way of getting the evaporation, but it does not give a fair idea of what the boiler will do for a number of hours at full power. To show this feature, ten consecutive hours have been taken for each boiler, and, in addition, a correction has been made for the feed-water at 120° instead of the temperatures during the trials.

MAXIMUM PERFORMANCE FOR TEN HOURS.

	Ward.	Cowles.
Apparent evaporation per hour from feed temperature of 120° at 160 pounds pressure	22,050	18,200
Actual evaporation under above conditions (correction made for moisture and superheating)	19,105	14,192
Actual evaporation per hour per square foot of heating surface	7.724	7.002
Horse-power for which one of the boilers proposed for the "Monterey" will furnish steam (based on ratio of heating-surfaces) at 20 pounds of steam per I. H. P. per hour	1,189.5	709.6
Horse-power from the whole number of proposed boilers	4,558	4,257.6

In the decision as to which boiler should be used in the "Monterey," account was taken, not only of the relative evaporation per square foot of heating-surface, but of the relative weight for power developed, space occupied, facility for repairs, convenience of manipulation, etc., etc. Without going into detail, it may be said, as an inspection of the tables

will show, that in most of these items the Ward boiler came out ahead."

As a result of these tests the award was made to the writer, and the U. S. coast-defence vessel "Monterey" was fitted with a battery of four Ward boilers having a total heating-surface of 11,880 square feet, and 308 square feet of grate. These boilers are built for 200 lbs. steam, and weigh, including water, only 71.12 tons for the four.

This is the first installation of water-tube boilers on a large scale in the United States, and at the time of its inception (August 2, 1888) the general sentiment was very much opposed to this innovation. Great pressure was brought to bear against their introduction, by the engineering profession, by existing interests, and by the public press.

To our much-respected chairman, Commodore Melville, is the credit due of the adoption on a U. S. war vessel of tubulous boilers working under forced draught, and to his indomitable will in stemming all opposition we are indebted for whatever good may result.

In discussing the merits of tubulous boilers, Commodore Melville, in his annual report for the year 1890, thus succinctly presents the case:

"*As a result of these trials it was determined to place boilers of the Ward type in the Monterey, as they best filled all the conditions required, and a contract has been made for them.*

"The decrease in weight for a given power is but one of the advantages to be gained from the use of coil or tubulous boilers, though this alone would warrant their being used. Another and very important advantage in favor of employing them in war ships is that from the small quantity of water they contain and the perfect circulation, steam can be raised in a coil boiler, without injury, *in a very much less time than in one of the locomotive or Scotch type,* even though the latter be fitted with mechanical devices for forcing the circulation. With a coil boiler all the time necessary is that required to start and build up the fire, say half an hour, with soft or semi-bituminous coal. This point was kept steadily in view when it was decided to adopt boilers of the coil type for three fourths the power of the 'Monterey,' for the service she is to perform (coast defence) will require her to be ordinarily at

anchor or under easy steam; if she is under way, with the two Scotch boilers with which she is provided in use, she can attain a speed of about 10 knots; this can be increased to 16 in a half-hour by firing up on her coil boilers. Or if she is at anchor, with no steam at all, or only sufficient to run the dynamo-engine and other auxiliaries in constant use on a modern ship, *she can in an emergency be under way and running at a speed of 14 to 15 knots half an hour after fires have been started in the coil boilers.* To keep a ship with ordinary boilers in such readiness as this would be simply impossible unless she happened to be near a coal supply, for the fires would require to be kept so heavily banked that the supply in her bunkers would soon be exhausted.

"Coil boilers are cheaper for the same power than either the Scotch or locomotive type. They can be taken to pieces and shipped in comparatively small packages to a vessel in any part of the world; arrived at their destination, the old coil boilers (if the ship is so fitted) can be taken to pieces and hoisted up the fire-room hatch and the new ones lowered and connected together, all by the force on board. *They can be forced with greater safety than can a shell boiler,* since in a properly *designed coil boiler the circulation of water will increase with the intensity of the fire,* and if steam is washed off a heating-surface as soon as it is formed, no overheating or burning can occur. A serious explosion with this type of boiler is impossible.

"The use of boilers of the coil type in vessels of small displacement and enormously large power, like torpedo-boats and cruisers, is already a necessity, and, in my opinion, it will not be many years before their use will be general in all steam-vessels, merchantmen as well as men-of-war. The most serious objection to them is that they require clean fresh water for feed, but by the use of evaporators and filters this can be accomplished."

The trial of the U. S. coast-defence vessel "Monterey" has shown quite satisfactory results from the tubulous boilers. Worked in conjunction with the Scotch boilers, a good opportunity was afforded of comparing the results; both were worked under 4 inches of air-pressure in the fire-rooms, with no injurious results to the tubulous boilers. The full official results have not been published, but it is well known that the

results were most satisfactory, as shown by the following extract from the official report:

"A careful examination has been made also by the board of the Scotch and Ward boilers. In the combustion-chambers of the starboard Scotch boiler there was a slight bulging of the back-sheets between the fifth and sixth rows of stays from the top. Two or three tubes leaked slightly, and one seam slightly. The port Scotch boiler was not bulged at all, but there was a slight leakage of one seam, and two or three stay-bolts leaked a very little. With these exceptions the boilers are in excellent condition. The only defect noticeable about the coil boilers was the lower part of the inner edge of the door-frames, which in every case was burned off. From the general performance of the Ward boilers we are of the opinion they are well adapted to form the major part of the boilers in vessels of war."

In corroboration of this, a letter was received from the president of the Union Iron Works, in which he says: "The performance of your boilers was such that any one might be proud of. . . . We may say that we think the record of your boilers on the 'Monterey' has seldom been equalled and never excelled."

The relative boiler-power of the "Monterey" is:

Scotch—grate	88	sq. ft.
Heating-surface	2,840	"
Tubulous (Ward's)—grate	308	"
Heating-surface	11,880	"

While this is the first adoption of tubulous boilers on so large a scale in the U. S. Navy, there are many smaller vessels using them, among which may be mentioned the torpedo boats "Stiletto," "Cushing," and "Ericsson," besides nearly one hundred steam-launches.

The policy of the U. S. Navy Department is necessarily conservative, but it is clearly visible that there is a steadily growing tendency to the use of tubulous or coil boilers. No less than three gunboats are projected, in which the major part of the boiler-power is of the tubulous type—not to mention the torpedo-cruiser which was to have had eight tubulous boilers, but has not yet been built on account of the inadequacy of the appropriation.

As another evidence of the growing popularity of these boilers, it may be noted that at present two very large lake steamers are being built at the Globe Ship-building Works, Cleveland, O.,—length 380 ft., beam 44 ft., hold 30 ft. These vessels are to be equipped with quadruple-expansion engines of 7000 H.P., using steam at 210 lbs. furnished by 28 tubulous boilers.

The U. S. Revenue Marine, after using a Ward tubulous boiler, grate 53 ft., heating-surface 1655; engine $\frac{19\frac{1}{2} \times 30}{26}$, on the steamer "Manhattan," has specified the same type of boiler for two new vessels, one of which, the U. S. revenue cutter "Hudson," has recently gone through a most successful trial. In connection with this trial, it may be interesting to note that the "Hudson" is practically the same size and style of boat as the three tugs built by Harrison Loring for the U. S. Navy Department; the engines in all of the boats are triple-expansion, and of the same design and dimensions. The three navy tugs had Scotch boilers, while the revenue steamer "Hudson" was fitted with a Ward's tubulous boiler of the same style as those used in the "Monterey," resulting in a development of—

524 I.H.P. by the Ward tubulous boiler,
372 I.H.P. " " Scotch boiler;

152 I.H.P., or forty per cent, more power by the tubulous than by the Scotch boilers. The weight was 34,720 lbs. for the tubulous, as compared with 90,048 lbs. for the Scotch. The duration of the trial of the Scotch boiler was one hour at the dock, three hours in free route; that of the tubulous, twelve hours at the dock and four hours at full speed. The speeds were, respectively, 11.14 knots and 13.1 knots. This is not an exceptional showing. We have removed boilers of the old type, substituting tubulous, on from one third to one fourth the weight, which invariably results in a very considerable increase of speed. In one yacht the draught was lightened thirteen inches and speed increased one and one half knots by simply changing the boiler.

We may cite further, as an indication of the rapid introduction of tubulous boilers, that Manning's Yacht List shows

no less than 139 yachts as having tubulous boilers. Many of these are the largest and finest yachts, with boilers having from 1500 to 3000 square feet of surface. There is doubtless an equal number of yachts throughout the country using coil boilers, not registered in any club.

This steady growth is not limited to the United States. The Danish Government has recently completed trials of a third-class cruiser of 1300 tons displacement, called the "Gaiser," of 3000 I.H.P., fitted with *Thornycroft tubulous boilers* having 171 sq. ft. of grate and 12,000 sq. ft. of heating surface. There is a saving of sixty tons as compared with the "Hecla" of the same power. A mile more speed is expected as the result. The official report says: "*During the trials the boilers worked most excellently; steam was kept with the greatest ease.*"

The steam trials took place in the Sound at Copenhagen, and consisted of a six-hours' coal-consumption trial, an eight-hours' sea-speed trial, and a four-hours' full-power trial. The mean results obtained are given in the table on next page, taken from *Engineering*.

The English Government, following in the same wake, has recently built the torpedo-gunboat "Speedy," 230 ft. long, 27 ft. beam, 15 ft. depth, with a displacement of 810 tons. It has two sets of triple-expansion engines, $\frac{22'', 34'', 41''}{21''}$, designed for 250 revolutions with 210 pounds of steam, to be furnished by eight Thornycroft boilers, having 14,720 sq. ft. of heating-surface, 212 sq. ft. of grate, and is contracted to have 4500 H.P., which is expected to result in a speed of 20.25 knots. This gives the vessel 1000 H.P. more than any sister vessel of the same type having ordinary shell boilers.

It will be seen from these illustrations that whenever the highest results are desired recourse is necessarily had to tubulous boilers; and it is only reasonable to conclude that the practice that is being perfected on these smaller vessels, possessing such tremendous energy, will shortly be reproduced, on a much larger scale, on the largest vessels. The wedge is well entered; it has increasing pitch, and will soon "get there."

TRIALS OF DANISH TORPEDO CRUISER "GAISER."

	Coal-consumption Trial.	Sea-speed Trial.	Full-power Trial.
Date of trial	Oct. 27	Nov. 2	Nov. 5
Duration of trial.......hours.	6	8	4
Displacement of ship on trial.......tons.	1,265	1,259	1,276
Steam-pressure in boilers.......lbs.	167.0	176 0	177.6
Steam-pressure in high-pressure valve-chest... "	146.6	164.9	164.0
Steam-pressure in first receiver....... "	56.6	70.0	75.0
Steam-pressure in second receiver....... "	5.4	9.5	13.0
Vacuum.......inches.	26.5	25.3	25.1
Air-pressure.......inches of water.	Natural draught.	0.57	0.81
Revolutions of fans per minute	....	475	571
Ratio of cut-off	0.48	0.54	0.68
Mean pressure in high-pressure cylinders......lbs.	33.6	46.4	52.2
Mean pressure in intermediate-pressure cylinders.......lbs.	24.7	30.8	36.4
Mean pressure in low-pressure cylinders...... "	10.0	12.0	14.6
Mean revolutions per minute of main engines	204.7	227.9	250.6
Collective indicated horse-power	1,744	2,422	3,157
Mean temperature in forward funnel......deg. F.	423	466	585
Mean temperature in aft funnel.......... "	439	482	628
Mean temperature between boiler-tubes:			
Stokehold I (foremost).. Starboard....deg. F.	664	882	970
Port......... "	727	896	1,078
Stokehold II........... Starboard.... "	752	934	963
Port......... "	682	851	970
Stokehold III.......... Starboard.... "	639	815	876
Port......... "	670	828	901
Stokehold IV (after)... Starboard.... "	631	804	932
Port......... "	729	919	1,004
Total coal consumption on trial:			
Stokehold I........... Starboard.... lbs.	2,260	4,850	3,160
Port......... "	2,160	4,900	3,160
Stokehold II........... Starboard.... "	2,360	4,390	3,020
Port......... "	2,340	4,010	2,810
Stokehold III.......... Starboard.... "	2,320	4,170	2,780
Port......... "	2,210	4,040	2,760
Stokehold IV.......... Starboard.... "	2,310	3,940	2,900
Port......... "	2,310	4,270	2,990
Coal consumption per hour in all boilers... "	3,045	4,309	5,895
Coal consumption per hour per indicated horse-power.......lbs.	1.75	1.77	1.87
Coal consumption per square foot grate-area... "	17.8	25 2	34.5
Speed of ship.......knots.	14.34	16.00	17.1

Before concluding this paper some reference should be made to the design and construction of these boilers. Their form and make-up are so varied, it is difficult to classify them. They are of almost every conceivable shape, and of some it may be said they are wonderfully made. There is a liberty of design and form not allowable in the old shell type. They may be built to suit almost any shape—only limited by the fertility of the designer's mind. The essentials may be

classified as simplicity (as far as practicable), light weight, ample area, positive circulation, perfect workmanship, absolute provision for freedom of expansion and contraction of every individual part independent of any other, each tube having its own inlet and outlet—not too long or of too small diameter, easy of access, of interchangeable parts, and of suitable and first-class material; all arranged so as to have a low centre of gravity.

The facility of accomplishing these results has been greatly aided by the improvement in steel castings. In the early examples parts were welded or brazed together with miserable results. These difficulties are now easily overcome by using special designs of steel castings, which may be made in almost every conceivable form by careful design of flowing lines and even thickness. In our own practice we have found special helpfulness in the use of steel castings with great reduction of weight and increased compactness and strength. To make this more apparent, I have assembled a number of mild-steel castings of great variety, shown on Plate XVIII.

Numbers 2, 3, 4, and 5 are the base rings or foundation of the Ward launch boiler, ranging from 30 inches diameter in the smallest to 8 feet diameter in the largest. They are cast with all openings as shown; the smaller ones are not over $\frac{5}{16}''$ thick, while the largest range from $\frac{5}{16}''$ to $\frac{3}{8}''$ in thickness. Numbers 9 and 17 on either side are the vertical manifolds in the Ward marine boilers, and average $\frac{5}{16}''$ in thickness; numbers 6, 13, 22, and 24 are the body pieces of the Ward launch boiler, cast as shown with all the openings therein, which are reamed out and tapped; these range in diameter from 13″ to 38″, in thickness from $\frac{5}{16}''$ to $\frac{3}{8}''$. These castings are riveted to boiler-plate, bevelled and calked the same as homogeneous plate. Numbers 11, 16, and 17 are the horizontal manifolds of Ward marine boiler, and range from 3 to 5 feet in length; numbers 1, 8, and 14 are doors and frames, $\frac{1}{8}''$ and $\frac{3}{16}''$ thick; group 19 are various-sized drumheads, with reimbursed openings, from 13″ to 28″ diameter; group 12 represents manhole plates, respectively 14″ × 10″ and 32 pounds, 12″ × 9″ and 15 pounds, and 10″ × 7″ and 11 pounds; the middle size is $\frac{3}{16}''$ thick, and has frequently been tested to 450 pounds.

In the matter of shells or drums there is little difficulty. They are of small diameter, and made of high-grade steel plate, welded instead of riveted—the only riveting now necessary is in securing the heads. In the "Monterey's" boilers, which have each approximately 3000 sq. ft. heating-surface, there are not over 125 boiler rivets.

Tubes.—There is a diversity of opinion respecting the tubes—an undoubted leaning being towards the highest grade of tube made, namely, solid-drawn steel tubes, which are a beautiful product, but great doubt as to practical good results exist. They seem to be more subject to pitting than ordinary charcoal iron. Welded steel tubes appear to be out of the question. A most reputable manufacturer of tubes says they have not yet been able to obtain sheet steel which would weld satisfactorily into tubes. Experiments both in England and America have gone to show that good charcoal-iron tubes are most satisfactory.

The most serious trouble with tubes is pitting from the inside. How far this results from galvanic action, the action of acids deposited from oil uniting with other active agents and depositing in spots, or the lack of uniformity of the component parts in the metal, has not been determined. It is, however, a serious drawback to all boilers, attacking alike shell and tubulous. We have seen steel tubes removed from a Scotch boiler with holes $\frac{3}{8}''$ diameter after four months' use. Quite an important discussion took place before the Master Mechanics' Association at its recent Saratoga meeting on the character or merits of steel and iron tubes respectively. It was announced, in a report on this subject, that in the case of a large number of steel tubes, the results, so far as wear is concerned, have been unfavorable. The following definite experiment was cited: An engine was equipped with 114 iron tubes and 113 steel tubes, Dec. 20, 1890. The iron tubes were placed on one side of the centre and the steel tubes on the other side of the centre of the boiler, the tubes being divided by a vertical line through the centre of the flue-sheet. At the expiration of fifteen months the flues were all removed, the condition of the tubes being such that seventeen of the iron ones were condemned on account of pitting and corrosion, while sixty-four of the steel tubes were condemned for the same defect, the inferiority of the latter being thus largely

in excess of the iron tubes. On this account, and in view of their greater conductivity, composition tubes have been looked upon with great favor. Great care is necessary in the composition and perfect unity of the metals, as only the best are admissible. They are much to be desired for use on salt water, if only on account of freedom from oxidation. How far composition tubes may prove desirable for water-tube boilers is yet uncertain, but several makers are experimenting in this direction. Personally I am disposed more favorably to copper tubes than to composition for water-tube boilers, especially when they are expanded in. Our own experience for general purposes is decidedly in favor of charcoal-iron tubes. We have bent (cold), adjusted, threaded, erected into boilers, and tested six miles of tubes with a loss of only two tubes.

Joints.—Much has been said upon this much-mooted subject in opposition to screwed joints, joints in the fire, etc. For water-tube boilers there is no difficulty in attaching tubes by either expanded or screwed joints; all that is necessary is that they may be secure and tight under all conditions. An expanded joint if carefully made, with the pressure inside, ought not to, and does not, so far as we know, give trouble in water-tube boilers, largely due to there being no strain on them except from internal pressure; they are not stay-tubes and are not loaded with the pressure on flat tube-plates, pressing in opposite directions and held rigid only by the tube-joints. There is, however, no question in our minds that the screwed joint properly made is decidedly the most satisfactory in all positions: once tight, they remain so under the most trying condition of the strongest forced draught and high pressure. We use them under a combustion of 66 pounds of coal per square foot of grate and 250 pounds steam-pressure, in the hottest fire, feeding the boiler with cold water (65° Fahr.) with absolute impunity. The prate about screwed joints in the fire is simply bosh! There are 17,280 threaded joints in the "Monterey's" four Ward boilers—all in the fire, and after the several extended trials under 4 inches of air-pressure, there was not a leak.

With Scotch boilers, on the other hand, it is said that the "Bancroft" is the only U. S. vessel that has passed through the trial without showing some signs of leaks or stress from

the use of forced draught. The disaster to our English friends in this direction, as is well known, has been so serious as to cause the greatest alarm.

Operation.—There are some points in water-tube boilers which call for different management from that adopted in the old type of shell boiler. One point especially is the firing, which should be done by introducing small quantities of coal at regular intervals, keeping a *thin clear fire.* The coking system cannot be used; if it is, the larger combustion-chamber becomes a gas retort; the gas is produced and burns in the upper part of the boiler, smoke-hood, and stack, and is not only lost, but becomes a nuisance by making and wasting great heat. The firing should be so conducted that the gases are consumed at the instant of formation in the furnace.

Feed-water.—With our present steam-pressure, the use of salt water is entirely out of the question. Fresh water alone should be used in all boilers, and the water-tube in particular: not but that salt water may be used with reasonable care in conjunction with a surface-condenser in an emergency, but without the condenser—no!

With the increasing tendency to high pressures and piston speeds, *cylinder lubrication* contributes its share of care and attention. The oils of lubrication passing through the condenser are fed with the water to the boiler. The extent of the resulting evil depends upon the suitability of the lubricant. We have seen a water-tube boiler on the waters of New York harbor with an internal coating of greasy deposit $\frac{3}{16}''$ thick all through, after one season's use. On the removal of the coating, numerous tubes were found badly pitted, and the boiler was discarded, as the result of *gross carelessness.* Another boiler of the same type, which was well known to be coated internally with greasy deposit, did not lose more than one tube in five years—showing the desirability of suitable cylinder lubrication. This grease deposit is perhaps the most serious difficulty encountered by all boilers, water-tube included, and it is most desirable that efficient filters and purifiers be fitted to all boilers. We are glad to see them in our recent and finest vessels. This is considered of prime importance.

Endurance.—It is difficult to see why a boiler of the water-tube type, well built, should not be as enduring, with proper

care, as a shell or locomotive boiler. The mere fact of the water being inside instead of outside of the tubes would not seem to affect the longevity of the tube. A piece of metal of a given thickness ought to last just as long regardless of which side is exposed to the water; and, conditions of care and use being equal, we cannot see why the water-tube type should not last as long as those of the old type. As a matter of fact, the tubes in the Ward boilers are very much thicker than the ordinary boiler-tube, and on that account last longer. We have had one boiler in constant use fourteen years, during which time only *one* tube has failed. The yacht "Halcyon," fitted with a Ward boiler six years ago, when in the Fish Commission service, has not lost a tube. The yacht "Fedalma," similarly boilered five years, has not lost a tube. The U. S. revenue steamer "Manhattan," Ward boiler, five years' service, lost the first and only tube a few months ago. The yacht "Golden Rod," boilered five years ago, has not lost a tube; and so on with many others. The great obstacle to endurance in water-tube boilers is the *human one*. Water-tube boilers are comparatively new, and engineers have not by long experience been trained to their proper care, which the Scotch boilers have gained as the result of extended use and experience. When engineers and the public become as familiar with the care of water-tube marine boilers as they now are of the Scotch, the longevity will be in favor of the water-tube boiler.

Relative Efficiency.—Water-tube boilers occupying so much less space than shell boilers, we may reasonably hope that the necessary power for a ship may be obtained with greater economy. The saving thus far effected has been due more to efficient engines than boilers. The present ordinary boiler takes up so much room that the amount of boiler was determined chiefly by that which would furnish the necessary steam without being able to consider the highest evaporative efficiency. Under the new era we shall hope to see such ratios of heating and grate surface as will produce the most economic evaporation. This effort is clearly apparent in the recent instalments of the Thornycroft boilers on the "Gaiser" and the "Speedy."

It has been usual to estimate the value of boilers by their ability to burn coal per square foot of grate, and evaporate

water per square foot of heating-surface. We think the measure, in both cases, should be per square foot of heating-surface. We should like to see a uniform rating of marine boilers, of combustible matter, of evaporation, of weight and space occupied, per square foot of heating-surface, as the standard of value, leaving the matter of "H.P. per ton," "per square foot of grate," etc., out of the boiler question. We suggest the following basis of efficiency :

Combustible, Evaporation from and at 212°, Weight, Space,	} per square foot of heating-surface,

instead of Coal per square foot of grate,

I.H.P " " " "
I.H.P. per ton,
Heating-surface per I.H.P., etc., etc.,

which are all misleading, and often refer to engine performance as much as boiler.

There are some points we think should be well considered in conducting future tests of boilers, so that the comparisons may be more accurate. It is very important that a standard coal should be adopted for at least one test of all marine boilers,—say, for instance, New River, Pocahontas, or Cumberland,—a coal possessing as nearly as possible uniform characteristics, and then that one coal used on all comparative tests at the same rate of combustion per square foot of heating-surface. This is especially necessary when it is remembered that the percentage of foreign matter varies from one to twenty per cent in various coals, and that reduction of evaporation to "per pound of combustible matter" takes no cognizance of the heat lost through the presence and removal of that twenty per cent, which not only gives no heat, but abstracts it.

We would emphasize our remark as to test being made under a *uniform rate of combustion per square foot of heating-surface* of a standard coal by pointing out that "natural draught," so called, may mean anything depending upon the

character of the coal, the area, construction, and height of the chimney. This suggests the desirability of investigating two points which may largely affect the economy of boilers, namely, the rate of combustion which will develop the most heat units, and the area and height of chimney likely to produce with least loss this rate of combustion.

There are comparatively few accurate data upon the performance of marine boilers apart from the engines; those which are available have been ably tabulated by Assistant Engineer S. H. Leonard, U. S. N., and published in his paper on Tubulous Boilers in the *Journal of American Society of Naval Engineers*, which I annex (see opposite).

Passed Assistant Engineer R. S. Griffin, U. S. N., has formulated the following table from the same data, which "fines" the matter down.

"Taking the boilers given by Mr. Leonard, arranging them in the order of their rates of combustion, and introducing the Thornycroft boiler of the "Ariete," given on page 183, vol. L., of the *Journal*, we have:

	1. Combustible per sq. ft. H. Surface	2. Evaporation per lb. Combustible.	3. H. Surface per cu. ft.	4. Weight per sq. ft. H. Surface.	5. $\frac{1 \times 2 \times 3}{4}$
Ward (Launch)	.159	10.77	3.418	18.2	.443
Towne	.190	13.40	3.694	21.8	.431
Herreshoff	.301	10.23	2.945	14.8	.613
Ward (Launch)	.323	10.01	3.418	18.2	.836
Belleville	.501	10.42	1.228	53.2	.120
Thornycroft	.823	10.83	2.180	10.2	1.905
Scotch	.870	9.93	1.268	41.2	.266
Herreshoff	.930	8.68	2.945	14.8	1.606
Ward (Large)	1.122	8.44	3.391	12.3	2.615
Towne	1.148	6.77	3.694	21.8	1.317
Scotch	1.415	9.06	1.268	41.2	.395
Ward (Launch)	1.427	7.01	3.418	13.2	2.586
Locomotive	2.220	7.74	1.771	31.3	.973
Locomotive	2.728	7.35	1.771	31.3	1.134

The product of 1 and 2 is, of course, the evaporation per square foot of heating-surface; but as it is important to know the rate of combustion, the above form seems to cover all points.

The rate of combustion for the Thornycroft boiler is taken as that given by Prof. Kennedy, using the maximum rate, and allowing 5 per cent for refuse. For the locomotive boiler 10 per cent has been allowed.

In column 2 no deduction has been made for moisture.

The figures in column 5 are the result of multiplying those in columns 1, 2, and 3 together, and dividing the product by

BOILERS

TABLE FROM PAPER ON TUBULOUS BOILERS BY ASSISTANT ENGINEER S. H. LEONARD, U. S. N., PUBLISHED IN JOURNAL OF THE AMERICAN SOCIETY OF NAVAL ENGINEERS, VOL. II, NO. 2, MAY, 1890.

Type.	Dimensions.	Grate-area.	Heating-surface.	Ratio.	Comb'n. Per sq. ft. Grate.	Evaporation from and at 212° F. Per lb. Coal.	Per lb. Com'ble.	Per sq. ft. Heating-surface.	Per cu. ft. Space.	Per cent Moisture.	Weights. Empty, lbs.	Steam'g Level.	Per I.H.P.	Per sq. ft. Heating-surface.	Per lb. Water Evap'd.	Air-pressure, ins. of Water.	Steam-pressure, lbs.	Coal.
Belleville.	Length, 8′ 6″ Width, 7 0 Height, 11 0 Space, 654.5 cu. ft.	34.17	804	1 to 23.5	12.8	9.6	10.42	5.2	6.4	6.31	40,670	42,770	204	53.2	10.1	Nat'l.	111	Bitm's.
Herreshoff.	Length, 4′ 9″ Width, 3 8 Height, 4 0 Space, 69.6 cu. ft.	9	205.3	1 to 22	9.3 25.8	7.6 7.14	10.23 8.68	3.1 8	9.1 23.8	3.5	2,945	3,050	96 36	14.8	4.8 1.8	Jet. Jet.	120 195	Anth. do.
Towne.	Length, 2′ 6″ Width, 2 6 Height, 3 3 Space, 20.3 cu. ft.	4.25	75	1 to 17.6	4.3 24.5	10.46 5.6	13.4 6.77	2.7 8.2	10 30.4	......	1,330	1,640	172 56	21.8	3.1 2.6	Nat'l. 1.14	148 152	Anth. do.
Ward. (Launch type.)	Diameter, 3′ 2″ do. Drum, 1 7 Height, 7 2 Space, 42.7 cu. ft.	3.68	145.8	1 to 39.5	7.9 15.5 62.5	8.59 8.28 6.34	10.77 10.01 7.01	1.7 3.2 10	5.8 11 34.2	......	1,682	1,930	154 82 26	13.2	7.7 4.07 1.3	Nat'l. Jet. Jet.	0 17 161	Anth. do. Bitm's.
Scotch.	Diameter, 9′ 0″ Length, 9 0 Space, 572.5 cu. ft.	31.16	727.2	1 to 23.3	24.8 38	8.13 7.87	9.98 9.06	8.6 12.8	11 16.3	3.44 4.29	18,900	30,000	120 80	41.2	4.7 3.1	2.08 4.01	77 78	Anth. do.
Locomotive torpedo.	Length, 16′ 8″ Width, 6 4 Height, 7 6 Space, 630.3 cu. ft.	28	1,116	1 to 39.8	98.3 120.8	6.97 6.62	......	17.1 20.05	30.5 36.2	......	......	34,990	47.7 33.3	31.3	1.8 1.2	3.13 4.95	125 123	Bitm's. do.
Ward. (Large type.)	Diameter, 10′ 3″ do. Drum, 4 6 Height, 11 8 Space, 729.3 cu. ft.	53 66.5	2,473.5 2,490	1 to 46.6 1 to 37.4	55.04	8.03	8.44	9.47	33.1	11.6	26,533	30,474	26	12.3	1.3	2	160	Bitm's.
Thornycroft. (U.S.S. *Cushing.*)	Length, 10′ 0″ Width, 7 0 Height, 8 0 Space, 560 cu. ft.	38.3	2,375	1 to 62	45	......	......	......	......	......	20,160	24,640	31	10.3	......	3	245	Bitm's.

those in column 4. This is based on the assumption that each factor is of equal importance."

Commodore Chas. H. Loring, U. S. N., who conducted the competitive test on tubulous boilers, formulated the results as follows, now published for the first time:

A COMPARISON OF THE RESULTS OF TESTS OF THE WARD, THE COWLES, AND THE SCOTCH BOILERS OF THE "SWATARA," EACH MADE WITH AN AIR-PRESSURE EQUAL TO 2 INCHES OF WATER COLUMN.

(The cubic contents of the Ward and the Scotch boilers are taken as 90 per cent of their least circumscribing parallelopiped, including a two-inch covering on the Scotch boiler, this covering not being included in the weight.)

	Ward, pounds.	Cowles, pounds.	Scotch, pounds.
1. Coal per square foot heating-surface per hour	1.1795	.93204	1.0658
2. Combustible per square foot heating-surface per hour	1.1224	.80278	.87172
3. Water evaporated per square foot heating-surface per hour	6.8093	5.7376	6.9710
4. Equivalent evaporation, from and at 212° and at atmospheric pressure	8.2941	7.3287	8.7678
5. Evaporation per hour per cubic foot of space occupied, from and at 212° and at atmospheric pressure	18.6075	14.0188	8.396
6. Evaporation per hour per ton of steaming weight from and at 212° and at atmospheric pressure	1485.4	1209.8	455.762

	Relative Values.		
	Ward.	Cowles.	Scotch.
1.	1	.79069	.90360
2.	1	.71528	.77665
3.	1	.84261	1.02374
4.	1	.88360	1.00888
5.	1	.71153	.45122
6.	1	.81446	.30682''
Total	6	4.75	4.47
General average	1	.7916	.7450

DISCUSSION ON TUBULOUS OR COIL BOILERS.

SECRETARY McFARLAND:—I have placed on the blackboard part of a table which I compiled about two weeks ago as the result of all the most reliable experiments I could find with tubulous boilers; the complete table I shall hand in for publication in the Proceedings. I have not included a number of well-known boilers, among them those by Roberts, Mosher, and Almy, simply because I could find no published results of evaporative tests; perhaps no such results have been published.

The object of the table is partly to show how the evaporation varies with the air-pressure, but also to show the weights of the various boilers for a given power. Data of two types of cylindrical boilers and of a locomotive marine boiler are added for comparison.

I may say in this connection that our friend Mr. Ward has been ill for some time, and, fearing that he might be unable to prepare his paper, I prepared one myself, so that the subject might be brought up for discussion, even if this resulted in the demolition of my effort, for I feel that this is one of the most important subjects before us. Since Mr. Ward's paper has been read, however, mine would be superfluous, except the table, and that is submitted.

I was greatly interested, a few years ago, in hearing Mr. Ward tell how he went about the invention of his boiler. It was not an inspiration, nor an evolution of his inner consciousness, but a methodical study of the essential conditions of successful steam-making. Having studied all he could find on the subject and all the patents for boilers, he prepared a list of all the features of a theoretically perfect boiler. Some of these were of course incompatible. Further study led to a second list, showing the possible and compatible features of a nearly perfect boiler. This he endeavored to build.

The point on which I should like to hear discussion is that of durability—the extent of the useful life of the coil boiler. On this, it seems to me, depends the introduction of this type of boiler into every-day use on war vessels and in the merchant marine.

Our experience has already shown that they can stand any

COMPARISON OF VARIOUS TUBULOUS AND SHELL BOILERS.

Kind of Boiler and Maker.	Tubulous. Thornycroft.				Tubulous. Towne.		Tubulous. Cowles.	Tubulous. Ward.	Shell. Cylindrical double-ended.	Shell. Cylindrical single-ended.	Shell. Locomotive.	
Where Used	U. S. S. "Cushing."				Test on Shore.		Test on Shore.	Test on Shore.	U. S. S. "Newark."	S. S. "Iona."	Italian Torp. Cr. "Tripoli" and "Folgore."	
Outside dimensions	10′ × 7′ × 8′				6′9½″ × 5′4″ × 8′		11′5″ × 7′9″ × 12′2″	10′3″ diam. 11′8″ high.	13′6″ diam. 19′5″ long.	13′3″ diam. 10′ long.	16′8″ × 6′4″ × 7′6″	
Grate-surface, square feet	38				15.6		47	38	135	21	28	
Heating-surface, square feet	2451				577.0		2026.75	2473.5	4185	1580	1116	
Ratio heating-surface divided by grate-surface	64.5				37.0		43.12	46.67	30.99	75.2	39.8	
Weight of boiler empty, tons	9.00				3.57		9.75	11.84	57.80	29.30	......	
Weight of boiler and water, tons	11.00				4.52		11.55	13.85	80.12	47.17	15.60	
Duration of trial, hours	2.5	11.5	11.5	1.0	6.25	6.5	12	12	8	16	......	......
Air-pressure in inches of water	*0.0	0.5	3.0	4.0	†0.0	2.0	2.00	2.00	2.25	‡0.2	3.13	4.95
Feed-temperature, degrees Fahrenheit	52	58.5	58	52	45.3	39	58	50.4	......	106	......	......
Steam-pressure (above atmosphere), lbs	250	250	250	250	160	160	160	160	125.5	165	125	123
Coal per hour per square foot of grate-surface, lbs	7.58	24.12	40.23	66.32	14.35	33.78	40.19	55.05	40.00	22.4	98.3	120.8
Refuse, per cent	6.11	8.04	7.53	6.27	10.65	8.82	13.87	4.84	3.80	2.9	......	......
Moisture, per cent	8.09	2.11	3.89	6.68	8.66	10.62	......	12.48	......	2.87	......	......
Superheating, per cent	....	....	....	....	......	......	5.7	......	......	......	......	......
Apparent evaporation from temperature feed at temperature steam per lb. coal	10.55	8.13	7.58	5.69	6.36	5.30	6.16	6.60	Water not measured.	9.15	......	......
Same from and at 212° Fahrenheit	12.95	9.93	9.19	6.98	7.78	6.51	7.45	8.04		10.68	6.97	6.62
Actual evaporation from temperature feed at temperature steam per lb. coal	9.69	7.96	7.23	5.30	5.82	4.74	6.16	6.00		8.90	......	......
Same from and at 212° Fahrenheit	11.90	9.72	8.84	6.51	7.12	5.82	7.45	7.31		10.20	6.97	6.62
Actual evaporation from and at 212° Fahrenheit per square foot of heating-surface	1.40	3.63	5.51	6.70	2.76	5.32	6.96	8.62		3.06	17.20	20.09
Horse-power per 100 square feet of heating-surface on basis of 20 lbs. of steam per hour from and at 212°	7.00	18.15	27.55	33.50	13.80	26.60	34.80	43.10	55.90	15.40	86.00	100.45
Horse-power per ton of boiler and water, on same basis	15.6	40.44	61.38	74.65	17.60	33.90	61.07	76.98	29.20	5.16	61.52	71.85

* Blowers discharging into open fire-room. † Smoke-pipe 21.6′ above grate. ‡ Smoke-pipe 52′ above grate.

amount of forcing without the slightest injury. From the table you will see that the Ward and the Cowles boilers were each subjected to trials lasting 24 hours under two inches air-pressure, the Ward burning 55 lbs. and the Cowles 45 lbs. of coal per square foot of grate. The Thornycroft boiler was tested under Commodore Loring's direction on the U. S. torpedo-boat "Cushing" under pressures as high as four inches. This pressure was maintained only a short time, but the test under three inches pressure lasted nearly 12 hours.

These were all very severe tests; but we have recently had a test even more severe with the Ward boilers on the contract trial of the U. S. S. "Monterey," where they were subjected to a high air-pressure, and, as Mr. Dickie can tell us (he was on board during the trial), there was no trouble with them. After the trial was over, there was not a leaky tube or seam or anything of that kind about them, so that I think the question as to their standing any amount of forcing is settled.

Coil boilers are the lightest possible type of steam-generators, and the only question remaining as to their extended use is, as already remarked, whether they will have a reasonable life. They are composed mainly of thin tubes, and we have found in boilers of the ordinary cylindrical type that the average life of steel tubes is about three years. If this is the limit of life for a tubulous boiler, its prospects of speedily replacing the ordinary type are not so good. I may say, however, that the revenue steamer "Manhattan" has one of Mr. Ward's boilers, about five years old, in which the tubes are lasting very well; and I am informed that some of his boilers are more than ten years old.

I trust that this question of durability may be thoroughly discussed.

MR. E. E. ROBERTS:—In regard to the question of the life of a tubulous boiler, I will say that I met in Chicago a gentleman who bought from me in 1881 a steam-launch 50 ft. long, which I had used for nearly two years, the boiler of which was built during the winter of 1879–80. That boiler was my first crude attempt at making a tubulous boiler, or, as we then called it, a coil boiler. It weighed very much more than those which we are now building. This gentleman told me that the boiler had never had any repairs except new grate-bars and other fittings. It has been in use for thirteen years now, in the summer-time, and has been laid up in the winter, which I consider much more severe upon it than if in continuous service without forcing.

The last speaker has mentioned the fact that he had no public

records of our boilers in regard to evaporative efficiency, rate of combustion, etc. We have built 546 boilers, but I do not think we have ever had one in stock long enough to permit of a test.

There are a great many points which I should like to call up for discussion, but our time is so restricted to-day that it will be hardly possible.

I think the position of the downflow columns in a boiler of this character is of considerable importance. Theoretically, I should judge, they ought to be placed externally to the casing, so they would have no tendency to make steam by radiation from the fire. Practically, that seems to be impossible for many reasons, one of which would be the difficulty of removing the jacket.

The capacity of the downflows should, from my experience, be equal in area of cross-section to that of the combined areas of all the upflow pipes or tubes.

One important point which Mr. Ward heretofore has apparently borne in mind, is the delivery of the water from the upflow heating-surface at or near the water-line of the boiler, as it produces a much more rapid and scouring circulation, thereby having a greater tendency to keep the small tubes clean.

In the Thornycroft, and boilers of that type, the circulation does not commence until the difference of gravity between the upflow coils and downflow pipes is greatly increased. I have tested the circulation of one of *our* boilers by means of glass tubes, and found that there was a rapid circulation even before steam commenced to be given off. The evaporating water has not to be lifted to a greater height than the water-level before producing a circulation. Water, in boilers of the Thornycroft type, has to be extremely rarefied; in fact, it has to be largely steam before it can be lifted to a point where it can fall through the drum and give off its steam before reaching the water-level.

Another point for discussion, it seems to me, would be the restriction of the circulation by frictional resistance through the upflow coils, depending upon the diameter of the tubes, the number of turns, and the length of the tubes. I have been very much astonished in some cases in regard to that. I built our boiler for a natural-draught boiler, but I have known it to be tested with muddy water in the Ohio River under 200 lbs. steam-pressure, the engine cutting off at $\frac{1}{8}$ of the stroke, and probably releasing at from 160 to 180 lbs. in the stack, with a soft-coal fire. That boiler has been in use for three summers and has never developed a leak. The coils have been taken out for examination, found clean, and not only that, but in the bends they have actually been polished on

the inside by the circulation carrying grit through. The sediment pockets have collected all the mud, and it has been discharged from the blow-cocks. I may say, however, that the boiler was owned by a gentleman who is an engineer himself, and who cared for it himself.

The question of the test of pipes or tubes may also be brought up. I see no way of testing them except by hydraulic pressure, and in effecting an adequate test I should judge that at least 1000 lbs. to the inch should be applied. It is a question in my mind as to whether that weakens the tubes or not.

THE CHAIRMAN (Engineer-in-Chief MELVILLE):—How about pitting?

MR. ROBERTS:—We have had no trouble with that, except where it seems to be effected by tannic acid in the water derived from the roots of cypress-trees in Florida. We have had no pitting except in the feed-heating coils. None in the upflow coils at all.

The remark as to the life of the tubes in a tubulous boiler being but three years, brought to my mind the fact that it is not as much trouble to renew the tubes in a water-tube boiler with screwed joints as it would be to renew the tubes in a Scotch boiler, and probably at less expense. The main part of a tubulous boiler still exists, as it would in the case of the Scotch boiler, and the tubulous boiler would probably be more worthy of repair. I think the tubes will last fully as long in one type as in the other. The question of screwed joints is the one that will excite more interest than will anything else. We have made, I suppose, 300,000 of them, and I never knew one of them to have a serious leak, unless there was some defect in the fittings or bends, and this was always remedied before delivery. One of these screwed joints is the last part of the boiler we expect to leak. M. Belleville, I understand, experimented for several years before perfecting his boiler, but finally adopted screwed joints. I believe that quite a number of the French transatlantic steamers have used his boilers some years, notwithstanding their weight. We find no other joint equal to them.

In regard to the stopping up of the upflow tubes, or other parts of the boiler, by means of sediment, I would say that we prefer to sell our boilers for use on the muddy Mississippi River and its branches rather than anywhere else, although they are doing very good work on the Lakes and also the coast. The scouring effect of the grit in the water seems to get rid of all the scale.

I think that Mr. Ward will agree with me that the greatest trouble that we have to encounter is the lubricating-oil mixed with

the feed-water, which forms a very bad scale unless it is eliminated, which can be done to some extent by the use of filters; but this is not always done, and many of our customers do not see the necessity for it. That difficulty has not been by any means excessive, however. The discussion on leaky tubes in Scotch boilers, during which Mr. Dickie suggested the use of screwed joints for same, and the fact that we have made some 300,000 of such joints without any difficulty, gives me the impression that this idea would cover the whole difficulty with the tube-sheet, especially as all of our upflow pipes are screwed into the curved shells of our steam-drums, which are certainly no thicker than the tube-sheets of Scotch boilers, and the latter have the advantage of a flat surface, which will admit more complete screw-threads in the same thickness of plate.

[At this point, the hour of adjournment was reached on Thursday, and Mr. Roberts gave way to resume on Friday.—EDITOR.]

MR. ROBERTS:—In connection with the remarks made yesterday on the question of scale, I would like to say that I had a peculiar experience. An upflow coil of one of our boilers had become clogged with grease and dirt from the condenser, which stopped the circulation of water in that coil, with the result that steam had been formed on each side of the dam or plug, and driven the water out of the coil in both directions, so that the pipe became very hot and burned up the plug. Circulation was then resumed without bursting the pipe, the water sweeping the ashes, or residuum of combustion, through the coil, and showing nothing in the coil after it was cut out. The pipe was, however, swelled by the pressure while soft. Without careful thought, it would have been assumed that it had not been stopped up by the sediment and oil.

The question of elasticity and equal expansion throughout, caused by circulation, is important. There is no question at all but that a boiler delivering its water at the water line, or thereabouts, is heated equally throughout in a very few moments after starting a fire. There is no question of unequal strain (as in shell boilers) for that reason.

I wish some of the gentlemen present would take up the question as to the influence on the circulation of increased height in the upflow and downflow coils, all other things being equal as regards frictional resistance, etc. A question in my mind is, whether the extra height of the boiler will increase the circulation directly as its height, or as the square root of its height. I am somewhat gratified in looking over that tabular statement on the blackboard this morning, as with a Roberts boiler having about 40 sq. ft. of grate

(the proportion of heating-surface being about 35), using soft coal, with 30 ft. of smoke-stack and natural draught, the weight of steam passing through the engine was at the rate of just about 4 lbs. per square foot of heating-surface, or 140 lbs. per square foot of grate-surface per hour. That is a mere calculation, that was not tested by weighing the feed-water. The feed-water was about 80° F. This appears to compare favorable with other boilers, and encourages me to believe that a scientific test will demonstrate that public opinion is not far wrong in regard to the evaporative and, possibly, economical action of the Roberts boiler.

MR. E. PLATT STRATTON:—The sectional type of boiler for marine purposes seems to appeal strongly to engineers for adoption on the ground of their ability to carry higher pressures of steam on decreased weight, since the shell boiler, carrying 160 lbs. of steam, including the water it contains, will weigh fully 85 lbs. per square foot of heating-surface; this, when compared with about 20 lbs. in the water-tubular for much higher pressures, appeals strongly in favor of the latter, not only on account of economy in weight, but also in the decreased cost of fuel consumption per horse-power to be developed with the increase of pressures. Designers of water-tubular boilers have discovered that, unless very short tubes are used and both ends are open for the egress or ingress of water, the circulation seems to be defective; and when long tubes are utilized, it seems to be necessary to place them at an angle of at least fifteen degrees from the horizontal. Since this principle has been adopted I think the water-tubular boilers have been more successful. Probably the heaviest water-tube boiler that we know anything about, which is used so successfully in the French Navy, is the Belleville. Its tubes, however, do not stand at an angle of over three or four degrees from the horizontal; its success is therefore largely due to a stimulated circulation supplied through the steam-drum above, from which the feed passes downward through a column entirely outside the heating surface. Mr. Charles D. Mosher of New York, to whom I have referred in previous remarks, is with us this morning, and I trust he will expatiate on this particular type of boiler, since he has certainly succeeded in a remarkable degree in obtaining a greater amount of power from less weight of material than any engineer I know of, viz., on 19 lbs. of weight per horse-power.

MR. ROBERTS:—I cannot agree with the last speaker in regard to the allegation that 15 degrees of angle on the Belleville tubes are necessary to produce an adequate circulation. We have had two boilers in one vessel, each occupying a space in the form of a cube of nine feet. The upflow coils are composed of 1½-inch re-

drawn pipe (1½-inch internal diameter); the pitch of the pipes was 4½ degrees, and their total length was in the vicinity of 50 feet, with a downfall of perhaps 7½ feet. The question of angle I do not think should be considered any more than it should under similar circumstances in the draught of air through a boiler. The circulation is caused, not by angle, but by the difference of weight, all other things being equal,—I mean the difference of weight between the water in the downflow and those in the upflow pipes, like two different weights in a scale, without any regard to the angle whatever. The only extra efficiency of the angle of the upflow pipes (or tubes) is caused by this angle necessarily increasing the height of the boiler, and thus increasing the height, and consequently the weight, of the downflow column—at least this is the result in Roberts boilers. The water is *pushed* up through the upflow coils by the superior weight of water in the downflow columns. The angle does not affect this action, except by making the bends in the coils less abrupt. We use the angle on our larger boilers for this reason, and also to bring the lower pipes of the upflow coils nearer to the fire without reducing the height of the downflow columns or increasing the height (and consequent length) of the upflow coils by the addition of more pipes, which would increase the frictional resistance to the flow of the water.

Mr. H. B. Roelker:—The statement was made just now that the Belleville boiler was practically equal in weight to the shell boiler. Some time ago I mentioned to Mr. Myers Coryell, the representative in this country of the Belleville boiler, that somebody had made such a statement. He answered me, that in almost every case which he thought of just then, and especially in the case of the Belleville boilers which are being put into the new passenger-steamers of the Great Northern Railroad, building at Cleveland, there was a saving of fully 33 per cent in weight compared with shell boilers, which had been designed for the places and had been replaced by the Belleville boilers.

The statement that there is a forced circulation in this boiler is also inaccurate. The feed is injected openly into the steam-drum, and it descends through the circulating-pipe by natural gravity and not by any jet arrangement.

Mr. Stratton:—I think there is a hydrostatic pressure there due to difference of head, which has the effect of forcing the circulation to a certain extent, and as regards a saving in the weight in the Belleville boiler, I think it is attributable to the decreased amount of water that it carries per square foot heating-surface rather than to the reduced weight of the boiler itself. The tubes

are very thick and heavy. In the Belleville boilers now building at the Globe Iron Works, Cleveland, for the two fast steamers of the Great Northern Line, under the personal supervision of Mr. Miers Coryell, the two lower rows of tubes in each element are $\frac{37}{100}$ of an inch thick. The other tubes are $\frac{20}{100}$ of an inch thick.

MR. ROELKER:—No doubt that is so, that the weight of the water is included in these calculations.

MR. STRATTON:—I think it is more due to the decreased weight of the water than to the weight of the boiler itself. While on the subject of water-tubulous boilers for marine purposes, attention should be called to an instance that occurred a number of years ago which has caused many engineers to approach this problem very cautiously. I refer to the trials of the water-tube boilers in the SS. "Propontis," an English vessel, I believe, engaged in the East India trade, and later on the SS. "Montana," engaged in the transatlantic trade. Water-tubulous boilers were placed in each of these vessels, and by reference to *Engineering* of that date it will be seen that these boilers failed, especially in the matter of circulation. The lower ends of the tubes burned out, and the result was a financial disaster of a rather heroic character.

MR. GEO. W. DICKIE:—One of the most remarkable things to my mind in connection with this Congress is the way in which the subjects that are treated broaden out beyond the limits of the papers that originated them, and no subject that has come before this Congress has partaken more of this character than the subject we are now considering—that of coil and tubulous boilers, where the water is in the inside of the tube surface, and the fire on the outside.

Any one coming from the seaboard of the United States, or from the ship-building centres of Europe, to a meeting like this, is at once impressed with the vast differences in the treatment of such subjects. We have met here on the shores of the fresh-water seas of this continent and the great rivers, and when we come to talk on a subject like boilers on board ships, we meet new ideas, and we meet people who have a different condition of things to face; and we are rather astonished at the manner in which things are done, and at the character of the machines that are used for accomplishing their purposes.

Speaking with Mr. Howden yesterday, he expressed the same opinion,—that he was perfectly astonished at the way in which subjects widened out and took on new shapes as they were treated here in this Congress, and that this will form the chief feature at this meeting of engineers in Chicago,—a feature that has not

come into the councils of engineering meetings before,—while a marine boiler to us is an entirely different thing from what it is to gentlemen who are building these boilers for use in fresh water.

Mr. Ward referred to the disastrous results that followed any attempt to force matters with the Scotch boilers. I do not think that that is quite fair treatment of an old servant which has been with us so long and has served us so faithfully, and especially coming from a new competitor who has not quite entered the field. I think those who listened attentively to what Mr. Howden had to say yesterday would come to the conclusion that the Scotch boilers can be subjected to forced draught at high pressures without disastrous results.

There are difficulties, there are dangers, and there are certain conditions to be watched and attended to in regard to the working of these boilers, that require the best skill in order to get the best results from them. But as regards disaster, I do not think that any engineering production subjected to the strain that marine boilers are subjected to is freer from disaster than they. I think all owners of steamships will bear me out in this assertion.

There is one thing that I do not like in connection with most water-tube boilers, and that is the very limited water surface from which steam is liberated; and that, I think, brings up the question of obtaining comparatively dry steam from water-tube boilers. It was only by keeping the water very low indeed in the Ward boilers that we were enabled to get through the official trial of the "Monterey;" and even with the water very seldom in sight in the gauge-glass we had continual spats of water coming over, which very much militated against the efficiency of the engines. In the developed curves from the trial data there were peculiar notches, and these notches represented those spats of water which came over from the boilers.

In watching the separator, it would run along for a few moments perfectly dry, and then it would fill in such a way that it could not be relieved, and had to go through the engines. That I attributed to the want of water surface.

The efficiency of the water-tube boilers has not been established; that is, they have not been proved superior to the Scotch boiler in evaporating water. I do not think that economy in a steam-boiler can be attached to any particular type. It is a matter of grate and heating surface, and the proper distribution of the surface so as to take up the heat that is liberated from the fuel. I think that this matter has been settled.

A very elaborate test is now being made in San Francisco be-

tween two types of water-tube boilers and a boiler of the ordinary fire-tube class. The result of this test has not yet reached me, but I will endeavor to have it here in time to form an appendix to this discussion.

With water-tube boilers on board steamships much greater care will have to be exercised in regard to purifying the feed-water than in the Scotch boilers. The presence of grease in a Scotch boiler is dangerous enough; but the amount of grease in a Scotch boiler that we could get along with would be fatal, I think, in most of the types of water-tube boilers with which I am acquainted.

Another point that is brought up as something very much in favor of the water-tube boiler is the high pressure that can be carried without giving trouble. Now that is all very well in its way; but the troubles with very high pressures do not begin and end in the boiler or in the fire rooms. There are very grave troubles with high pressures—I mean pressures over 150 pounds —in the engine-rooms, as well as in the boiler-room, and I do not think we are prepared yet to take care of three or five hundred pounds of pressure in the engine-room. As a rule, it is quite high enough now to take care of.

The "Monterey" boilers were cited as an instance of the complete success attending the use of water-tube boilers of large size. Now I do not think that the use of the water-tube coil boilers of the "Monterey" can yet be taken as a guaranty of the success of that type of boiler. While we had the "Monterey" in our hands we used the water-tube boilers as little as possible. I think Mr. Melville repeatedly urged us to use the water-tube boilers, requesting us to make the preliminary trials with them, and use them as often as possible. We used them a little, and that little enabled us to see just wherein the difficulty with these boilers lay. On the official trial of the "Monterey" the vessel was under steam with the Scotch boilers about two hours before the Board of Inspectors came on the vessel, and not until they had made all their arrangements and were ready to begin their official trial did we light the fires in the water-tube boilers. We had found that the efficiency of these boilers would fall off after the first two or three hours very rapidly. This I do not believe to be an inherent quality of the boiler itself, but in this particular case it resulted from difficulties in firing—the difficulty of managing the fires as they were arranged in these boilers; the very large grate-surface, which is circular with the grate-bars radiating from the centre, making it very difficult to clean the fires. The ash-pans were very low, the fire-grate not more than 15″ above the fire-room floor, making it

exceedingly difficult to see the condition of the fires, so that we found we could obtain the best results by not lighting these boilers until the actual moment for the necessity of the work came around.

Unfortunately, the only cruise of any length that this vessel has made—that to Puget Sound and back, steaming, I should think, about 3000 or 3500 miles—has nearly all been done with the Scotch boilers; the water-tube boilers having not been in use for any appreciable length of time during that cruise. There appears to be a hesitancy on the part of the engineers to use them.

There is another difficulty, and one which affects the matter of weight a great deal. The radiated heat from the shell enclosing these boilers, owing to the very light brickwork inside the shell, is so great, that I think it is now proposed to put another casing outside, having a space filled with non-conducting material, so as to make it possible to use these boilers with some degree of comfort in the fire-room. Now this adds very much to the weight of the boiler. We also found that the rejected heat in the uptakes was very excessive when the boilers were pushed, and I think that is shown quite clearly on the table presented here of comparative evaporation between different types of water-tube boilers. It will be noticed that, in the Thornycroft boilers, the evaporation came down very rapidly as the boiler was pushed.

These are the points that strike me in connection with this. I do not present them here because I am opposed to the water-tube boiler. But I think that the water-tube advocates claim advantages for their boilers in certain directions that are not advantages. A boiler with a small amount of water in it is not a nice boiler to take care of. In the "Monterey" we had to station a man at each check-valve during the official trial, and his position was no sinecure, as the utmost vigilance had to be exercised to keep the water from getting either too high or too low.

Now I think it is absolutely necessary in a boiler that is to be safe, that you can vary its conditions: start the engines or stop them; take steam in large quantities or in small quantities at short intervals of time. You must have an accumulation of heat, and that can only be obtained by having a comparatively large amount of water in the boilers. It may be that in the Scotch boilers we have too much accumulation; but it is a fine thing when you have to stop and start, that steam is not made too rapidly or too slowly.

These have all got to be taken into consideration, especially when such a class of boilers is compared with a boiler that has served our purpose, and served it so well for so many years. [Applause.]

COL. SOLIANI:—In regard to this matter of tubulous boilers, there is, I think, one more point deserving consideration, viz., the power of water-tube boilers in comparison with that of ordinary marine boilers. In a cylindrical double-ended marine boiler it is possible to develop from two thousand to three thousand indicated horses, and even locomotive boilers have been constructed capable of supplying steam for nearly two thousand indicated horses, while no such power has yet been obtained from one single tubulous boiler. As far as I know, five hundred indicated horses is the maximum power of a tubulous boiler at present. This is a point in favor of the cylindrical boiler, because it is more easy to work few boilers together than to work many. For instance, with an engine of 8000 I.H.P., four double-ended boilers may be sufficient, while as many as sixteen water-tube boilers would be required, and probably some of these boilers would kick. In my opinion it is better to drive four big horses than sixteen ponies.

MR. H. B. ROELKER:—I would like to make one remark regarding the assertion that there is no reserve power in tubulous boilers. At the Quintard Iron Works, New York, they have a comparatively small Belleville boiler which is attached to the steam hammer and other machines working interruptedly, and it has worked with entire success in that connection. The Belleville boiler, however, is provided with special apparatus for that purpose.

ASST. ENGINEER W. H. P. CREIGHTON, U. S. N.:—I should like to ask Mr. Dickie if he thinks there is any relation between the wet steam of the "Monterey's" boilers and the fact of the tubes being horizontal. Any one knows that in a boiler with crowded tubes the steam rises irregularly and in large bubbles, and where you have a boiler with bad circulation you are very likely to have very wet steam. Now in these horizontal coil boilers is there not an accumulation of steam which suddenly breaks out and carries the water with it? Do not those land boilers in which the tubes are inclined 15° or more give comparatively dry steam?

MR. GEO. W. DICKIE:—I do not know that I can answer that. I was simply referring to the condition of things on the "Monterey,"—the difficulties that we had to contend with. Why these difficulties were present, I think it would be the place of the water-tube boiler advocates to find out. We had the difficulties, and we had them only when the water-tube boilers were in service. We have a great many installations of water-tube boilers. I am of the opinion generally that when you have to force the water-tube boilers beyond quite a low rating of their capacity, you begin to be

troubled with an excess of water in the steam. That is my experience in regard to the use of water-tube boilers when they are pushed.

MR. E. PLATT STRATTON:—I do not think there is any difference of opinion pervading the minds of engineers on the matter of wet steam in water-tubulous boilers, since it is generally conceded that the water has to rise in gulps with the steam in its passage from the heating-surfaces to the point of liberation. Mr. Mosher, in dealing with the conditions affecting water-tubulous boilers, seems to have been thoroughly conversant with every detail. I refer especially to the form of his downtakes, and his method of taking steam from the steam-drum. He has shields or dry pipes, or, probably more properly speaking, separators, by which he insures comparatively dry steam to his engine; and I think with the limited amount of liberating surface that there is in all water-tubulous boilers, that it is imperatively necessary to have a separator of some kind between the boiler and the engine to overcome the conditions incident to the entrainment of water. It was recognizing this condition that induced me to go upon this field some years ago, and develop a separator which is still in successful competition on the market, and seems to meet with general approval, although I have long since disposed of all interest in it. I think a water-tubulous boiler, if it is to be operated long and successfully, requires apparatus to take the entrained water out of the steam before it can be used in the engine.

MR. C. D. MOSHER:—In my opinion the prime object of the water-tube boiler is to carry a high steam-pressure. In a properly designed and constructed boiler there would be no difficulty in carrying 300 or 400 lbs. pressure, although our engines have not yet got to the point of utilizing this pressure after it is furnished.

There need also be no trouble on the score of foaming under very high air-pressures, say 8 or 9 inches, with proper design. A large releasing area can be provided by having a great many tubes entering the steam-space of the boiler, but above the water-level, so that there is no tendency to lift the water when driven hard, as in boilers of the ordinary type.

I have designed a boiler embodying these principles, and in a test by Prof. Denton of Stevens Institute, and while we were forcing it so as to give an evaporation of about 8½ lbs. per square foot of heating-surface, the moisture in the steam was only 1½ per cent.

As Mr. Ward's paper is not in print, and its reading just now has necessarily been hurried, I am not prepared to discuss it as thoroughly as I would have liked. If permissible, I should be

glad to submit some further details about my boiler, the principles on which it is designed, and some very interesting tests under very severe forcing. These I could submit in writing, to be incorporated in the discussion when published.

THE CHAIRMAN:—We shall be glad to have your contribution. Our aim is to make the Proceedings of the greatest possible value, and we shall be glad to have all the gentlemen who contribute to the discussions elaborate their remarks when revising them.

MR. JOHN C. KAFER:—In discussing the water-tube boiler, making a comparison with our old friend the Scotch boiler, I think Col. Soliani has touched on a very important point. If it were not for getting lightness in a boiler, I think that we would all turn to the Scotch boiler and use it to the exclusion of any water-tube boiler that I know of. The object of using the water-tube boiler is to get maximum power for minimum weight. In doing that we sacrifice very many good qualities in the Scotch boiler that have proved very valuable to us. But one thought in Col. Soliani's remarks I wish to bring forward a little more, and that is the commercial disadvantage of the tubulous boiler. It is undoubtedly true that it takes twice as much care to attend to two things as it takes to attend to one, and if we have 16 boilers instead of 8, it will take twice as many men to attend to them. Commercially that means a great deal in the operation of ships. It costs a great deal more to run our merchant ships than it ought.

No matter how economical a tubulous boiler may be in coal consumption, if the cost of labor for the proper care of the boiler be taken into consideration, the boiler is not a commercial nor a financial success.

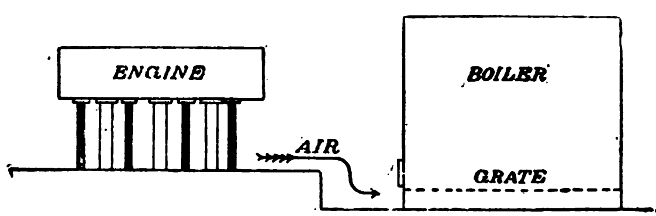
MR. JOS. R. OLDHAM:—Wherever a good old servant is found, one that has served his country for many years, there are sure to be detractors, who whilst ignoring his virtues and usefulness are ever ready to remind you of his faults or shortcomings. I think the Scotch boiler stands in a similar position, in a mechanical sense, to that character. For instance, in this room I think we could find a dozen men who could tell you of having had charge of Scotch boilers steaming continuously for ten or twelve thousand miles without any mishap or even great inconvenience in steaming.

Now is there a man here that will tell us anything of the working from his own experience of a large battery of water-tube boilers on a long voyage at sea. If so, I think it would be very useful information, as there are many friends of the Scotch boiler who are ready to be convinced of its defects. As it is, I fear my experience has been unfortunate.

I saw the "Montana's" and "Dacotah's" boilers and several of "Perkins'" patent boilers fitted on board of the ships. I also know something of the first set of boilers fitted on board of the "Propontis." In addition to these I may mention the "Shaw," "Mace," and "Turner" patent boilers, all of which were quickly removed from nearly new vessels, at great loss to the owners, and in some instances to the boiler-makers also. The latter types, I may explain, had more or less brickwork in the formation of their combustion-chambers or fire-boxes.

Now let it be clearly understood that I am not condemning all types of water-tube boilers, for many of these are doing well in small vessels on fresh-water seas, and there may be a great future before them generally; indeed their universal adoption is assured if higher steam-pressures prove to be economical. But the point I desire to make is this: exactly the same extravagant claims in the way of economical working and lightness were made in favor of the "Montana's" and "Propontis'" boilers about twenty years ago; or indeed rather more pretentious claims were put forward in those days than now, our friends the inventors having become more modest as the coal-saving patents have increased in numbers—possibly because they saw that when the aggregate gain promised by the numerous inventors was looked into it appeared that the saving by adopting most of such schemes not only reached one hundred per cent, but, if all were true, the marine boilers and engines could be worked for less than nothing by the adoption of such devices.

MR. A. G. MATTSSON:—It seems to me you can have satisfaction on a smaller scale. The objection to the Scotch boiler is its weight, and in many cases the cost. Now in regard to the tubulous



SCALE $\frac{3''}{16}$ = 1 FT.

boiler I will give an example of the steam-yacht that I built the engine for last year (about 300 horse-power engine), the grate-surface is about 40 sq. ft., and we got easily 300 horse-power with hard coal and natural draught. This boat has been running very successfully, both this summer and last, without having any trouble

in the least from the boiler. The only trouble we experienced was in regard to getting a sufficient amount of air to the grate, which I will illustrate: Here is the engine (E); here the boiler (B). The boiler, for some reason, was placed so that the ash-pit came below the level of the engine-room floor, causing the supply of air to be very imperfect. Finally, the boiler was lifted up 18″, and after that we got all the steam we wanted, and the boiler has been run successfully. It was the Roberts boiler. I may mention another example, the yacht "Idler," having an engine of about 300 horse-power and a Roberts boiler containing 40 sq. ft. of grate-surface. This boat is now completing her fourth season with the boiler mentioned, without having had any trouble from the boiler. No doubt with us the conditions are different from those on the sea. We do not have such long runs, and, furthermore, it is hard to get the boilers where and when you want them. We have only a few first-class boiler-shops on the Lakes—one in Buffalo, one in Detroit, one in East Saginaw, and two in Cleveland; and with the shipyards dotted all around the lakes, it is often difficult to transfer a heavy boiler to the place where the ship is being built. You can only ship boilers not to exceed 11 ft. 6 in. diameter on the railroads, and it would avoid considerable trouble and expense to use a reliable tubulous boiler, which can be built almost anywhere, in place of the Scotch boiler, which requires such enormous shops for its construction.

I think I am expressing a general opinion on the Lakes in regard to tubulous boilers.

Secretary McFarland (submitted after the meeting):—I happened to be called out of the room while Mr. Dickie was speaking, and thus did not hear his unfavorable comments on the Ward boilers of the "Monterey," or I would have replied at the time. There are several points to which a complete rejoinder can be made, and I feel that the importance of the case merits that they should be stated.

Before doing so, however, I may remark that Mr. Dickie does not controvert the main point I tried to make, which is that, although the boilers were forced very severely, 4 in. air-pressure, there was not a leak or mishap of any kind. This is surely a matter of first importance, for, as matters are now going, the boiler that will stand most forcing without injury will be, other features equal, the best.

It is very true that our Chairman, the Engineer-in-Chief, urged the Union Iron Works to make all their preliminary trials with the Ward boilers, because he felt it of great importance to have the

firemen and others become accustomed to them *before* the contract trial. The very fact, to which Mr. Dickie has alluded, that the boilers contain very little water, makes it necessary that the firing should be regular.

After my reference to Mr. Dickie's presence on the "Monterey" during her trials, it might seem ungraceful for me to attempt a contradiction of what he says, and I would not do so but for the fact that we have received very different accounts at the Navy Department, and, while I know that Mr. Dickie means to be entirely fair, I think that what I shall say will show that he was misinformed. By his own statement, he was in the engine-room, and therefore could not know by personal observation what was the regimen of the boilers. His statements, therefore, are based either on inferences (as in the case of his mention of the action of the separators) or on reports from others.

Now, in each of those fire-rooms we had a naval engineer officer, who staid there during the entire trial; and their testimony in official letters to the Navy Department is that the performance of the Ward boilers was admirable, and the water-level was steady. They attribute whatever of dissatisfaction there was to inefficient firing, saying that the fires were not properly handled, and that the firemen seemed to have no personal interest in the success of the trial. So well did the boilers perform, that one of these officers remarked that he believed it would be good policy to remove the two Scotch boilers and replace them by a fifth Ward boiler, when he was sure that all the steam needed could be furnished.

With regard to the inference, based on the separators, that water was carried over from the Ward boilers, I would simply remark that all six of the boilers, the four Ward and the two Scotch, were connected, and I do not see how any one could tell that the water in the separators came from the Ward rather than from the Scotch boilers. It is by no means unusual for the latter to carry over water.

I have recently received a letter from one of the engineer officers of the "Monterey," in which he says: "There is no trouble about carrying over water if the stop-valve is set right and water handled half-way decently. One feed-pump can be made to supply both the Ward and the Scotch boilers working in battery, but every chump who calls himself a water-tender can't do it."

But we have still further evidence of the satisfactory working of the "Monterey's" Ward boilers. Some time after the contract trial the Department directed a 48-hour trial of the machinery, during which Mr. Forsyth, the assistant manager of the Union Iron Works,

was on board. This time the regular firemen of the vessel did all the work. Although without much experience with coil boilers, they did so much better than the firemen on the contract trial, that Mr. Forsyth said that the latter would have been a complete success if the firemen of the second trial had been on board at that time.

Mr. Dickie says, regarding the trip to Puget Sound, during which only the Scotch boilers were used: "There appears to be a hesitancy on the part of the engineers to use them [the Ward boilers]." Mr. Dickie would not have made this statement, which is wholly unwarranted, had he known the facts regarding this Puget Sound trip, which I shall now give.

For some reason, unknown to me, one of the New York daily papers has never lost an opportunity to disparage the Ward boiler. More than a month after the contract trial, this paper, not being able to criticise the Ward boilers for making too little steam, charged that they generated so much steam as to endanger the Scotch boilers (to which, as I have already stated, they were connected). I need not go into the details given, which were so utterly ridiculous as to show the absurdity of the story. However, about this time the administration of the Navy Department changed, and this paper called the new Secretary's attention to the alleged dangerous condition of the "Monterey's" Scotch boilers. The Engineer-in-Chief explained to the Secretary that the whole story was a myth, but advised, in order that the whole matter might be set right, this trip to Puget Sound, *the Scotch boilers only to be used, to show their complete integrity*. This is why they alone were used on that trip.

I think these statements answer pretty thoroughly the points raised by Mr. Dickie; but, while treating the subject, I may remark that the revenue steamer "Hudson" has one Ward boiler of about the same size as those on the "Monterey." Her contract trial took place recently, and Mr. Collins, the consulting engineer to the revenue service, who conducted the trial, assures me that the water-level was as steady as in any boiler he ever saw, and that, with the throttle wide open, not a particle of water was carried over. It is true that this boiler was not forced as hard as those on the "Monterey," but I cite the case to show that the water-level is easily kept constant.

MR. CHARLES WARD (reply sent in after the meeting):—In reply to Mr. Roberts' question about the downflow of the circulation, I may say that it is not material that it be outside the boiler, and away from the heat, as in boilers of the Thornycroft, Normand, and Yarrow types; nor is it necessary that it should be of the same area

as that of the aggregate of the upflow tubes. In the Ward launch boilers the downward current is through one fourth of the regular tubes,—this being determined by the feed of lower temperature being delivered into this set of tubes.

In the Ward sectional boiler, with the downcast tubes in the centre of the system, the amount of circulated water is very great, as from its construction the water is necessarily carried over with the steam; whereas in the Thornycroft and the Ward launch boiler very little water circulates, due to the fact that each tube extends well up above the water-line, delivering only its own steam, which is dried and possibly superheated when delivered into the upper drum.

Some years ago, when Mr. Yarrow was in Washington, I showed him photographs of our Ward launch boilers; he was impressed with the fact that we obtained circulation without an external downcast. I see he has since discarded its use in his boiler, which I believe will work just as well without as with.

The statement that the circulation is caused by varying density is, to my mind, correct. It is precisely similar to the action in an ordinary chimney.

In regard to the inclination of tubes referred to by Mr. Stratton and others, I may say that our experience shows such an inclination necessary as will allow the steam to keep moving upwards, and thus avoid the overheating of the tube. We have known 3″ horizontal tubes to burn on the top from this cause.

Replying to the relative weights of Belleville and Scotch boilers, I would say much depends upon the Scotch boiler. The U. S. Navy Department has designed some very light Scotch boilers, but those of the average merchant steamer are much heavier. From the best data, I find they range from 40 to 60 pounds per square foot of heating-surface. The three Navy tugs referred to in my paper had Scotch boilers, which weigh 66.7 pounds per square foot of heating-surface in steaming condition. The " Monterey " Ward boilers weigh 14 pounds per square foot of heating-surface.

As to Mr. Dickie's remarks, we are glad to see his faithfulness to his old friends, the Scotch boilers. They have unquestionably been good servants,—we credited them as such,—but their day of usefulness is fast passing away. The burdens of increasing necessities are becoming too much for them. If the practice in marine engineering is to stand still, and we are to continue carrying 100 to 150 pounds of steam and run with moderate combustion, and are willing to hamper our vessels with hundreds of tons of needless

dead-weight, we may continue to use Scotch boilers; but if we are going to use 200 and 250 pounds of steam with triple and quadruple engines and forced draught, we shall find water-tube boilers our best servants.

With regard to the preference of our friend for the apparently larger water surface in the Scotch boilers, for liberating steam, I think he is in error. As a matter of fact, while the steam-space in tubulous boilers is unusually small,—exceptionally so,—the liberating surface is quite extended. The water constantly circulating presents an ever-fresh surface, from which the steam rises as it passes the drum; so that, in fact, it is ever changing, and consequently, of more area than is possible under the Scotch type.

As to the performance of the Ward boilers on the "Monterey," I have had the most complimentary reports, through various sources, from every official connected with the trial of the "Monterey," as well as from the builders of the vessel, through Mr. H. T. Scott, who voluntarily wrote me that "the performance had seldom been equalled and ever excelled." I can only say, as far as my knowledge goes, the Navy Department was well pleased with the performance of the tubulous boilers. From our own standpoint, if there was any priming at any time, I should certainly charge it to the Scotch boilers, because we do know that in one or two cases lately the trials of English ships have had their duty requirements lowered because of the impossibility of preventing the Scotch boilers priming under the higher duty. Under the circumstances, we are at a loss to know how Mr. Dickie determined which of the boilers primed.

It is hard to see how Mr. Dickie's remarks can apply respecting the firing of four hours' duration, when on the test boiler we ran twelve hours without cleaning and made as much steam at the last as at the first. I think Mr. Dickie's mistrust is due to a lack of more intimate acquaintance.

Col. Soliani has the impression that 500 H.P. is the unit size of a tubulous boiler, and that consequently there would necessarily be numerous connections to obtain large power. This point is well taken in some cases, but it is not always correct. The Ward boilers on the "Monterey" are 1100 H.P. each,—are only 11′ 6″ high. If it were permitted to build the tubulous as high as the diameter of the Scotch, there would be no difficulty in constructing larger tubulous boilers; though we think a 1000 H.P. is a large enough unit, and that smaller would be better than larger.

Mr. Stratton instances the prevailing opinion that the steam and water must rise together in tubulous boilers, and thinks a sepa-

rator necessary. Our friend's separators, I believe, find greatest patronage where Scotch boilers are used. In my own practice I have never found one necessary.

Mr. Mosher has undoubtedly produced the lightest boiler per square foot of heating-surface, and his accomplishments are certainly phenomenal in the way of speed; but the evaporation of $8\frac{1}{4}$ pounds of water per square foot of heating-surface is not unusual. In 1884 there was tested at the New York Navy Yard a Ward launch boiler that evaporated 10 pounds per square foot of heating-surface; but this even is not equal to some locomotive practice, though for present requirements it is sufficient.

As to Mr. Kafer's remark about the commercial advantage of the Scotch boiler in requiring less attention than the tubulous, I believe this would not occur when the installation of the tubulous boiler is as well thought out as the Scotch is, by long use; even were it so, it is more than counterbalanced by the loss from carrying tons of needless dead-weight.

In conclusion, I may say that no boiler or other human production is yet perfect, and the tubulous boiler is certainly not free from "all the ills that flesh is heir to;" but we are doing all we can to meet the requirements of the case and expect only the fittest to survive. Time will tell.

MR. MOSHER (contributed after the meeting):—The remarks which follow are rather in the nature of an original paper than of a discussion of Mr. Ward's paper, but it has seemed to me that I could best give my views in that way.

The production of a really satisfactory boiler for marine purposes is undoubtedly one of the most difficult problems which has to be solved. With the present high pressure of steam, and the probably still higher pressure that will soon be in general use, the boiler presents an entirely different problem, and what was satisfactory with the lower pressures and moderate demand of steam in a given space is becoming entirely inadequate. The present demands on a boiler are extremely difficult to fully satisfy, notwithstanding that its construction has already received the most careful study of the brightest minds which the engineering world has produced, together with practical experience and perseverance, with a fair amount of success under moderate pressures, slow combustion, and where there was no limitation of space and weight. But modern requirements are no longer satisfied with moderate-speed boats, and at the same time a greater amount of room and carrying capacity is demanded.

We at once look to those portions of the machinery where

weight and space may be lessened without sacrificing any of its power, and our attention is directed to the utilization of greater piston-speeds, quadruple-expansion engines, and higher boiler-pressures. I think that the engineering fraternity will agree that the practical limit of the pressures which shell boilers are adapted to carry ends at about the pressures required for the satisfactory working of the triple-expansion engine; and even at these pressures such boilers are not entirely satisfactory, and with forced draught their digestion seems to be suddenly impaired, especially at the higher pressures.

The quadruple-expansion engine is now being introduced, but one of the greatest obstacles is the inability to provide steam of a sufficient pressure to warrant its use. We now look to the water-tube boiler to fulfil this want. There are many water-tube or tubulous boilers which are quite satisfactory when worked under conditions similar to those the shell boiler has fulfilled. There are also some that are well adapted to the carrying of the higher pressures required, but when run with forced draught there appears to have been very few that have given complete satisfaction.

The element of expansion and contraction is undoubtedly one of the greatest sources of trouble that a boiler is called on to withstand. It is a practical impossibility to avoid a great range of temperature taking place in the general working of a boiler. This generally centres in the weakest parts, namely, the joints or riveted seams of a boiler, as for example in a screwed joint, the thread of which weakens the tube or pipe by reducing its thickness just as it enters the fitting or any rigid part of the boiler, and the continued springing due to expansion or vibration centres in this, which is the thinnest part, and crystallization or weakness results in fracture. Our only complete cure is to have absolutely no joints near the fire.

A satisfactory boiler to be used with forced draught is not one that will only withstand a plenum of air equal to 2 or 3 inches of water with the most careful handling. If it is found that in order to furnish the required amount of steam it is necessary to burn an average of 40 or 50 lbs. of coal per square foot of grate; it will be necessary, especially if the running is at all intermittent, at times to run with an air-pressure of 5 or 6 inches, or at the rate of 100 or more lbs. of coal per square foot of grate, and this is generally unconscious on the part of the attendant, as it is largely dependent on the condition and thickness of the fire. Even this high combustion will only be limited by the capacity of the fan to supply the draught. To continually withstand this intermittent, sudden,

and severe treatment, it is necessary to provide for a great amount of expansion in the parts thus exposed. However much provision may be made, and care and instruction be given to the attendants generally employed, it is almost impossible to so manipulate the fires as to avoid this great range of temperature taking place in the furnace, should there be a sudden demand for steam, or should that demand for steam be suddenly stopped when there is quite a heavy fire on the grates. At such times it is found that to control the rise or fall of pressure, particularly in a light water-tube boiler, it is necessary to suddenly go to either extreme of putting the full force of the blower on, with a heavy fire, or opening wide the fire-doors and putting the feed-pumps on at full speed. The effect of this severe treatment is principally on the furnace and tubes which are exposed to this very considerable range of temperature. It is imperative that the corresponding expansion of these parts be provided for, and it appears preferable to provide for this expansion to be taken up by elasticity. It certainly seems more mechanical for it to be taken care of by a curved or crooked tube rather than the tube-sheet, as happens when the boiler is constructed with straight tubes, whether they be attached to a flat or curved tube-sheet.

Another alternative is to make use of what are sometimes called elements. These are usually composed of steel castings. These castings are likely to warp or get out of shape. When there is a great range of temperature brought to bear on the different tubes, which are situated only a few inches apart at the point where they are attached to the tube-sheet, or its equivalent, their different expansion must be absorbed by the starting of the joints or distorting of the tube-sheets. Besides, they are very heavy, and liable to a great variation in thickness.

Another very important feature is that all generating-tubes or parts in the fire should be of small diameter, so if accidental rupture should take place only a small quantity of steam will be released, and a disastrous explosion avoided.

Should a tube of 3 inches diameter, as is advocated by the builders of some boilers, give out, especially with these extreme pressures, and in a closed stoke-hold, it is pretty sure to seriously burn or scald the attendants, while with a small diameter of tube, say 1 inch, there is comparatively little danger. Also, one of the most vital and important conditions, and one that has been almost always overlooked in the design of a boiler, is that the steam-drums, main body or part carrying the larger quantity of steam and water, should be placed entirely away from the fire, so that in case of that

part becoming short of water it will not become overheated and cause an explosion. Had this feature always been provided, many disastrous explosions would have been prevented, and many lives and much valuable property saved, and the general fear of high steam-pressures would not exist. It is also very important in a boiler to have a large water-level or surface area, so that in case its feed-supply is interrupted it will have a reasonable latitude of action without receiving any water.

The circulation in a boiler is of the greatest importance. In a boiler where the steam formed has to rise up through the water that is attempting to descend to replace that evaporated, the upward currents of steam conflict with the downward currents of water so that the heating-surface fails to be protected by solid water, and, besides being very inefficient, it is liable to become overheated, and rupture is invited; also priming and wet steam result. If a considerable quantity of steam is demanded per unit of surface, our only alternative is to provide separate passages for the water to return to the steam-generating surface; and these passages, it is found, must be placed outside of the furnace, and entirely away from the heat, otherwise steam will be formed in them, and in its attempt to rise will greatly retard the downward flow of the water. A steady water-level, with absolute certainty of its whereabouts, is of the greatest importance in a boiler, especially if forced very hard. In order to attain this, it is found necessary to deliver the steam as fast as it is formed directly into the steam-space of the boiler, and not below the water-line, as is the usual custom; as when all the steam is obliged to find its way up through the water contained in the steam-drum it is set into rapid evolution eddies and currents, and subject to great fluctuation, and the readings of the gauge-glass and gauge-cocks are very unreliable. When the above characteristics and conditions are avoided, pressures two or three times as great as those generally carried can be satisfactorily provided with absolute safety; besides, boilers may be run to several times their normal capacity with satisfactory results.

Another desirable feature in a boiler is to so arrange the heating-surface that the heat or gases of combustion shall impinge directly against or at right angles to such surface. The reason of this is apparent, as it is well known that air or the gases of combustion are among the poorest conductors of heat. Now, take the case of a vertical surface or vertical tube. The heat, starting near the bottom, is first considerably reduced in temperature, and forming a film or wall of the cooled gases encircling the tube, continues to envelop or protect its upper portions from the more

highly heated gases, unless this film of cooled gas is mechanically destroyed by the hotter gases impinging against it at a sharp angle. The same is said to take place, to some extent, when the gases pass through a horizontal tube, by forming a central core of the most highly heated gases while the cooler film continues to remain in contact with the tube; but an increase of their velocity or the intermittent action of the exhaust in a locomotive tends to bring the hotter gases in more intimate contact with the surface. This will partly explain the very efficient character of the heating-surface in a locomotive boiler.

While a great deal of attention has been given to feeding boilers, it would still appear that something further may be said regarding the introduction of the feed-water or the passing of it through the shell of the boilers.

There is a great divergency of opinion as to the proper place to introduce the feed-water into the boiler, some advocating the steam-drum both above and below the water-line, while others favor the water-legs or water-drums.

There is undoubtedly a greater range of temperatures met with where the feed-water is delivered into the steam-drum than when delivered into the water-legs or water-drums of the boiler. Even with an efficient heater and the greatest attention, there will be times when the feed-water is introduced into the boiler cold; and even if it is heated quite up to the limit of most heaters, say 212°, with the extreme high pressure, say 250 lbs., now demanded there will be a much greater difference of temperature between the boiler-plates and the feed-water than there is between boiling water and ice, and there is an undoubted danger of cracking the plates.

To assist in overcoming the evil effect of feeding cold water, I have devised a very simple arrangement whereby the cold feed-pipe and the cooling effect of the feed-water are not brought in contact with the plates of the boiler (see Fig. 5). This consists of a hollow boss with flange bolted to the shell of the steam-drum above the water-level. The feed-pipe passing through this boss, the inside of which is in contact with the steam, the cold feed-water is not brought in contact with the shell, or mixed with the boiler water until it has passed through a considerable length of pipe surrounded by steam.

Another great source of difficulty met with in a tubulous boiler appears in the form of pitting of the tubes. Why water-tube boilers should be troubled in that way more than boilers of other types, is difficult to determine. Yet this seems to be the universal difficulty, although in a boiler not under constant steam it would

seem that one reason why the tubes with the water inside and the fire outside waste away faster than those where the fire is inside of the tubes is because the constant corrosion that usually takes place on the side of the tube which comes in contact with the atmosphere causes a scale of rust, which is continually cracking off as the temperature varies. This occurs on the exterior or convexed surface of the tube, leaving exposed surface for further rust or corrosion to form; while with the water outside of the tube and the inside exposed to the atmospheric dampness this scale of rust, while it forms, is more likely to remain in contact with the surface, as on account of being enclosed in the tube it is prevented from cracking off, and acts as a protection against further corrosion.

It may be generally stated that the usual custom for cleaning the exterior of the tubes of tubular or water-tube boilers is by the use of the steam-jet, which I believe is also resorted to in almost all types of boilers while under steam.

It is also common practice in water-tube boilers to wash the tubes off by the use of a stream of water driven among the tubes with considerable force. With either of these methods it is essential to provide sufficient openings so that all parts of the tubes may be readily reached.

By the introduction, through the many cleaning holes, of a perforated pipe with hose connection, all parts of the tube surface may be readily reached and cleared of any soot. This soot either falls into the receptacles provided for that purpose or back into the furnace.

As the economy of a boiler is one of the most essential properties, we will turn our attention to this part of modern boiler practice. There appear to be very few directions in which to look for further economy. Principal among these are large and properly arranged combustion-chambers, and an arrangement and quality of heating-surface sufficient to reduce the gases of combustion to the lowest possible point before leaving the boiler; the heating of the feed-water; and the providing of a boiler that has no bad tricks within the scope of its regular duties, as well as when forced to its utmost, such as priming and uncertainty of the water-level; also, the range of abuse the boiler will stand without giving trouble, in the hands of the ordinary attendants.

One objection to a light, tubulous boiler, or one carrying only a small quantity of water, is its incapacity to store up large quantities of heat and the consequent fluctuation of pressure. This may be somewhat overcome by providing for a large amount of leeway through which the water-level in the boiler may be varied, and al-

lowing the pressure in the boiler to run up very much higher than the normal working pressures.

No doubt most of these requirements are familiar, but they have been mentioned here for the purpose of pointing out how well they have been cared for in the boiler I am about to describe.

Fig. 1 represents a sectional end elevation on line *CD*.

MOSHER'S PATENT WATER TUBE BOILER.
TRANSVERSE SECTION.

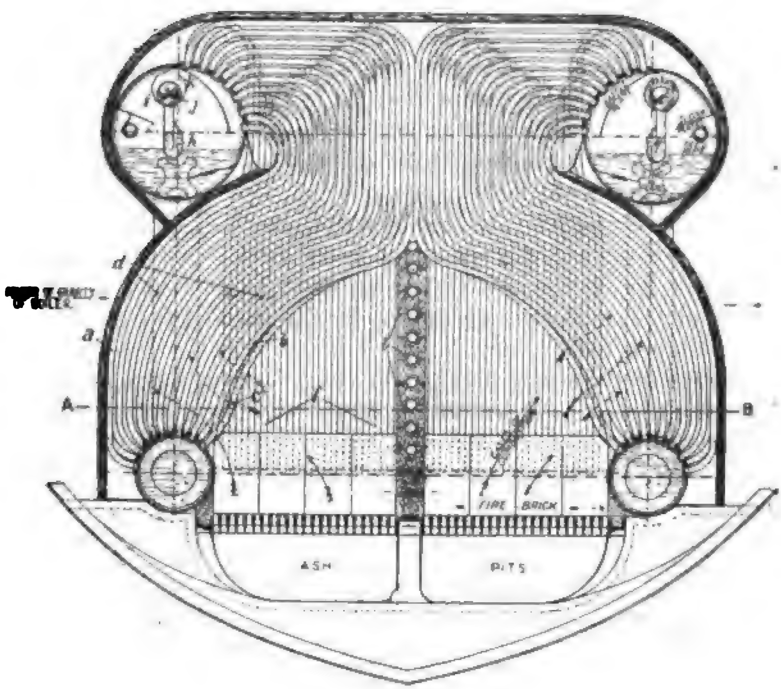


Fig 1

Fig. 2 represents a side elevation, with one section or half of the boiler and division wall removed.

Fig 3 represents a sectional plan on line *AB*, Fig. 1, showing furnace, its division-wall, and the return-pipes and generating-tubes.

Fig. 4 represents a side elevation, with one section or half of the boiler removed and division-wall in place.

Figs. 5 and 6 represent the end and side elevations, showing the boiler with the casing and fittings on.

By referring to Fig. 1 it will be seen that this boiler is essen-

tially composed of two independent sections, comprising two steam-drums placed over two water-drums at opposite sides of the furnace, and connected at each end by large return-pipes. The water-drums are also connected at each end by large cross-pipes. These cross-pipes have no free openings to each other, but are divided in the centre by blank flanges, by which the two sections are bolted

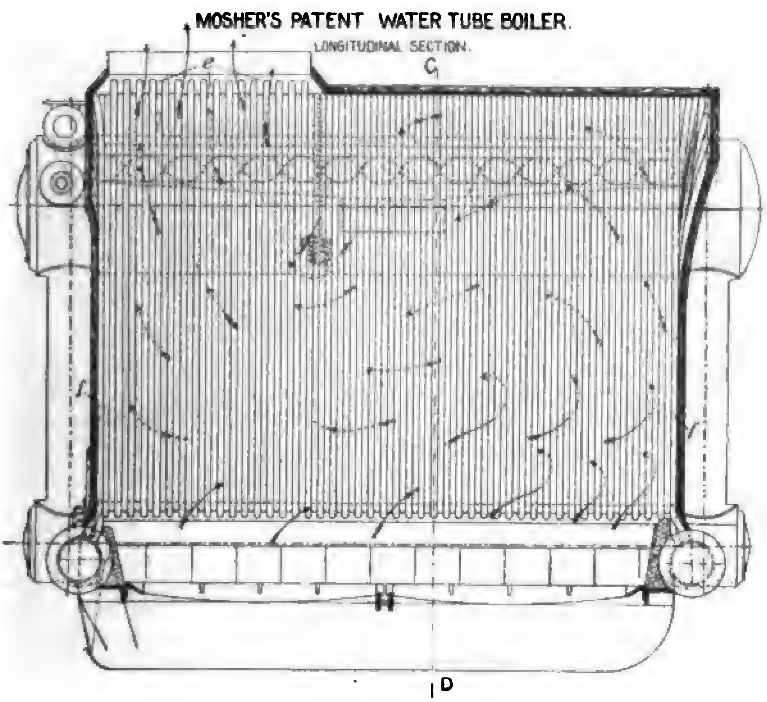


Fig. 2.

together. The steam and water drums are further connected by a great number of small generating-tubes arranged in loops forming the furnace of the boiler. These sections form a single furnace, which may be divided by a fire-brick division, thereby forming two independent boilers, which may be worked independently and treated as such in all respects.

Each section also has its independent feed-connections and steam-pipe. The generating-tubes are spaced their own diameter apart longitudinally, but in staggered rows where they enter the steam and water drums, while in the circumferential rows they are spaced a somewhat greater distance apart; that is, each tube in the alternate longitudinal row is placed opposite to the space between

the tubes in the row adjoining it. These tubes start from the water-drums and are bent in loops to form the furnace, then bent upward and outward to where they enter the steam-drums, as shown in Fig. 1.

In tracing the gases of combustion in this boiler we shall consider only one half or section. Each section of the boiler comprises a steam-drum, placed over its water-drum, which is connected

MOSHER'S PATENT WATER TUBE BOILER.
SECTION ON LINE "A-B" FIG. I.

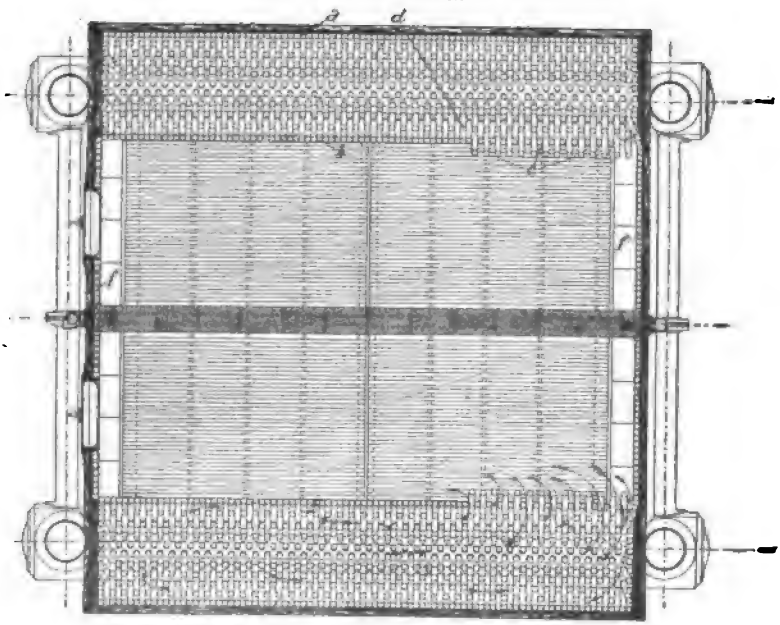


Fig. 3.

by a series of generating-tubes and large return-pipes placed at each end of the drums and forming a support for the steam-drums. These return-pipes are placed outside of the casing, and never come in contact with the fire. As before stated, the water-drums of each section are connected by large cross-pipes. These pipes are divided by blank flanges by which the sections are also divided, together with their casing, thus allowing either section to be placed in the boat separately, or removed in case of repairs.

By referring to Figs. 1 and 3 it will be seen that the two outer rows of tubes are bent between each other, forming a solid wall of tubes *a*, Figs. 1 and 3, extending the whole length of the boiler.

The two inner rows of tubes are also bent between each other, forming a solid wall *b*, Figs. 1 and 3. This wall, however, does not extend the whole length of the furnace, as a part of the tubes near the rear end are bent or staggered so as to form openings *c*, Figs. 1 and 3, through which the gases or products of combustion pass to the space between the outer wall *a* and the inner wall

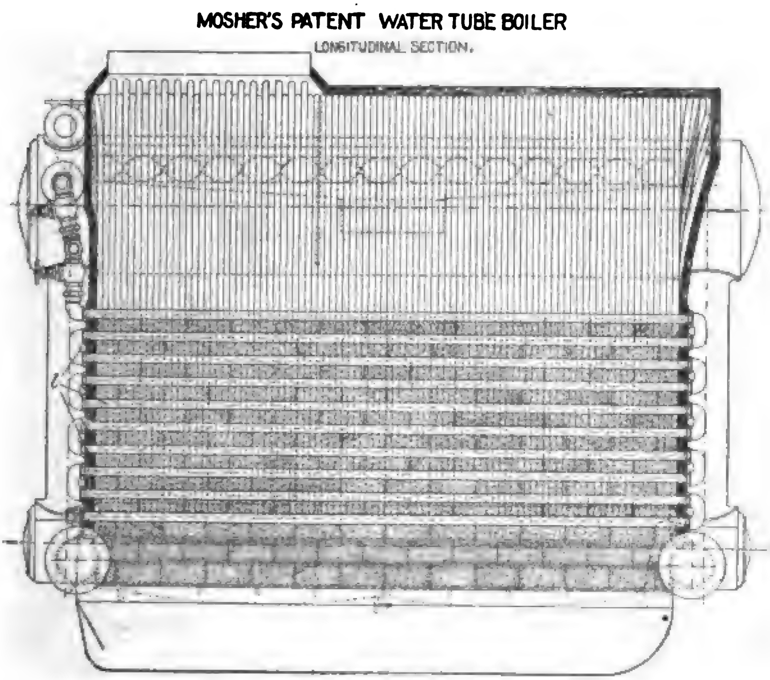


Fig. 4

b in Figs. 1 and 3, and among the intervening tubes. This arrangement presents a continuous wall of tubes, forming the crown-sheet and furnace, extending from the fire-door end of the furnace, compelling the products of combustion to pass from that end, as indicated by the full-line arrows in Fig. 2, to the opposite end of the furnace, where they pass through the broken or open row of tubes, as shown by the full-line and partly dotted-line curved arrows, Fig. 2, and full-line arrows, Figs. 1 and 3; while the wholly dotted-line arrows, Fig. 2, show the passage of the gases of combustion. After passing through the openings *c*, Figs. 1 and 3, they enter among the tubes *d*, Figs. 1 and 3, situated between the walls *a* and *b*, Figs. 1 and 3, and passing towards the fire-door

end of the boiler on their way to the stack, just before entering the stack, the gases encounter a baffle-plate *g*, Fig. 2, which extends across the upper portion of the flue formed by the two walls of tubes, and down somewhat below the centre of the steam-drums. The effect of this baffle-plate is to cause the gases of combustion to pass more intimately in contact with that portion of the tubes

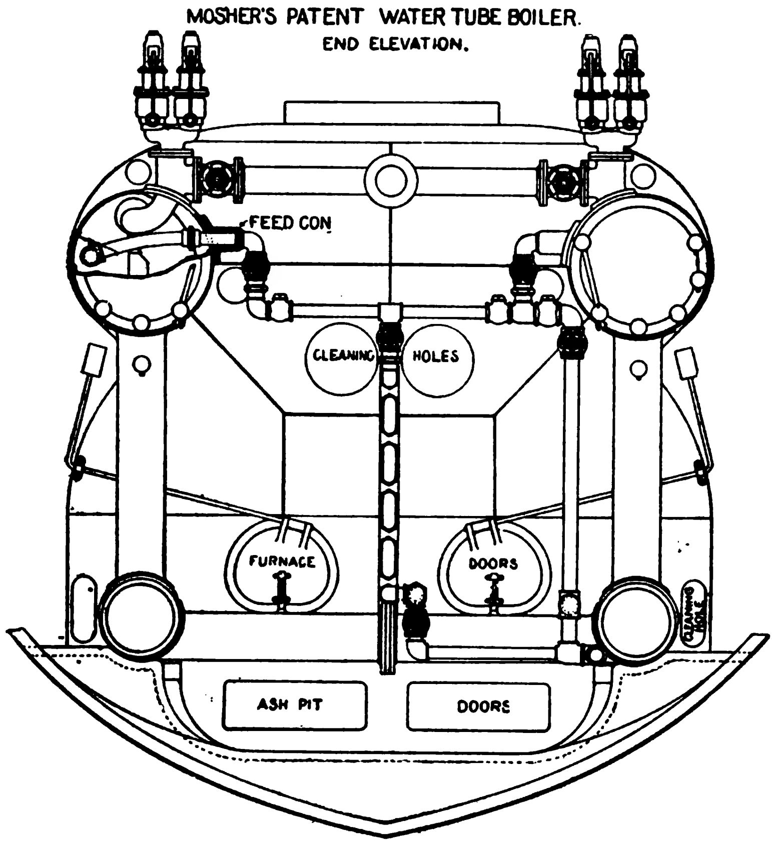


Fig. 5.

which is filled with solid water, and to prevent the hotter gases from coming directly in contact with that portion of the tubes which contains no solid water. At the lower rates of combustion the gases pass up among the upper portion of the tubes before meeting the baffle-plate, while at the higher rates of combustion the upper portions of the tubes only receive a sort of soaking heat. The hotter gases naturally take the shorter course, and pass in a more horizontal line under the baffle-plate, thence upward into the

stack through the openings or broken wall *e*, Fig. 2. There are also some small holes in the upper portion of the baffle-plate, which allow the stagnant or cooled gases to directly enter the stack.

There are other generating-tubes *f*, Figs. 1, 2, and 3, which spring from the cross-pipes.

These tubes are arranged in a staggered row as they start from

MOSHER'S PATENT WATER TUBE BOILER.
SIDE ELEVATION.

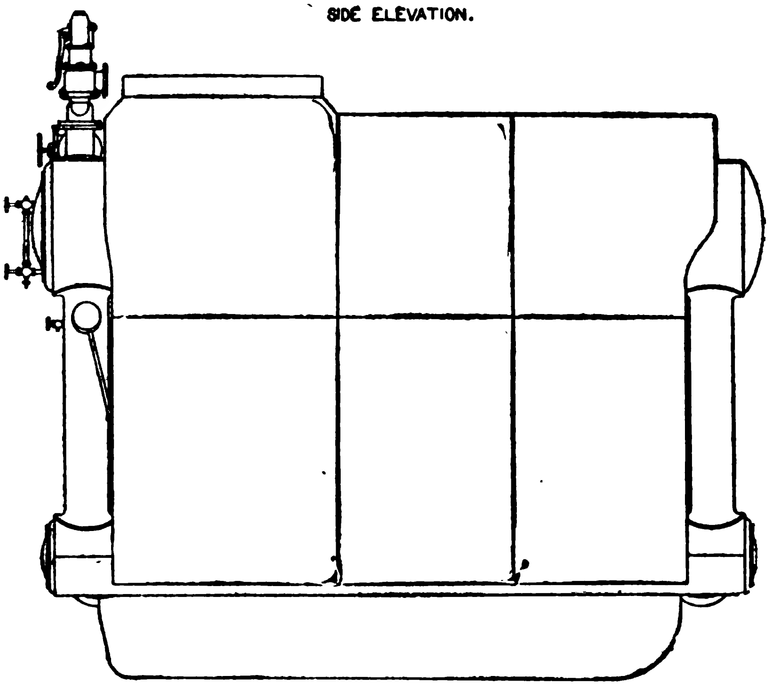


Fig. 6.

the cross-pipes, as shown in Fig. 2, and are then bent between each other to form a solid wall of tubes, forming the ends of the furnace, as shown in Figs. 1, 2, and 3. By further reference to Fig. 3 it will be seen that the entire furnace is surrounded by a solid wall of tubes filled with water, which prevents the intense heat from coming in contact with the casing.

The water circulation, it will be seen, takes place down through the large return-pipes situated at each corner outside of the casing, thence to the water-drums and cross-pipes, and up through the small generating-tubes, where it is converted into steam and delivered above the water-line into the steam-drums against a baffle-plate,

under which the steam is caused to flow, thence through the separator, shown in Fig. 1; also shown in dotted lines in Figs. 2 and 4, where any entrained water is removed before entering the steam-pipes.

The separator consists of a spiral tube *i*, Fig. 1, formed of sheet metal, the slot and overlapping edges pointing downward; this tube extends nearly the full length of the steam-drum. Within this tube, and extending its whole length, is placed a worm *j*, Fig. 1, or auger-form screw, formed by twisting a piece or ribbon of sheet metal, and is attached to the tube. One end of this tube is attached to the steam-pipe, while the other end is left open. A perforated hood *k*, Fig. 1, surrounds the upper portion of this tube, and the lower portion *h*, Fig. 1, forms a trap extending only a short distance in length, while the upper portion extends somewhat beyond the enclosed tube, both ends of the hood being closed, one end admitting the spiral tube to pass through it where it is attached to the steam-pipe.

In action the steam or vapor enters the perforations, which extend the whole length of the top side of the hood, and passes back through the space between the hood and the spiral tube, then enters the end of the tube, where it is caused to take a rotary motion by the worm or auger-formed screw, the centrifugal motion thereby created causing the water to be thrown to the outside, whereby the overlapping lip of the spiral tube catches any entrained water and delivers it through the trap below, where it overflows into the steam-drum. It will be seen that this separator really consists of several separators contained in one, as each convolution of the worm, in combination with the spiral tube, forms a separator of itself. A special feature of this separator, wherein it differs from all others, is that after the separation has once taken place the water of separation does not again come in contact with the currents of steam. In practice it is found to be very efficient.

The fire-brick wall that subdivides the furnace is held in place by several pipes *l*, Figs. 1 and 4, which are laid in the joints between the rows of bricks, which effectually locks them in place. These pipes are connected at each end by return fittings connected with right and left-hand thread couplings. These pipes act as a feed-water heater, the water being fed through them. In this way a large part of the intense heat in the fire-brick wall will be absorbed, which will greatly increase its durability.

Among the advantages possessed by this boiler are that the gases first pass the entire length of the furnace before entering among the tubes, enabling the fire to be worked to better advantage,

as it may be constantly pushed back, the fresh coal only being supplied to the door end of the furnace, and an incandescent fire maintained at the back end, over which all the gases of combustion must pass, and more perfect combustion be realized.

Another feature of great importance for boats having only one boiler, and especially torpedo-boats, is that in case of accident to a tube or the entering of a shot into one side of the boiler the remaining half may continue to furnish steam, and thus enable the boat to continue on its course; or, in the case of a torpedo-boat in action, this feature might enable the boat to make good her escape under conditions that would otherwise insure destruction were the boat fitted with only one boiler. By carrying the water considerably higher in one side or section of this boiler a boat may be trimmed to an even keel against a wind abeam, or other cause.

It can be readily seen that the boiler has a very low centre of gravity, which will be fully appreciated for use as a marine boiler. The boiler has no flat or stayed surfaces, or horizontal tubes or parts which are exposed to the fire, on which sediment may be deposited. The rectangular form of the boiler and the room required enables a very large amount of steaming capacity to be placed in a given space.

There are no seams or joints of any kind exposed to the fire. The return-pipes and steam-drums are virtually outside of the casing, as it will be seen, by referring to Fig. 1, that there is a solid wall of tubes besides the casing which passes between the furnace and the steam-drums, so that their explosion is impossible on account of low water.

There are no screwed joints of any kind in the boiler, all tube joints being expanded.

The form of the tubes will provide for any amount of expansion that can take place without bringing undue strains on the tube-joints.

The boiler is so designed that either half may be separately placed in the vessel, thus requiring a much smaller hatch than would otherwise be necessary; besides, it enables repairs to be made with greater facility.

The detailed report of the evaporative test of this boiler made by Prof. James E. Denton, of Stevens Institute, September 19, 1892, is as follows:

"The test was made to determine the most economical performance, at a moderate rate of combustion, with Pocahontas semi-bituminous coal. The draught was produced by a steam-jet, which caused a suction of ¼ of an inch of water at the base of the chim-

ney. The method of starting the test was to bring the boiler to regular action with wood, and then to draw the fire and start a new one with a weighed amount of wood, followed with weighed amounts of coal. At the end of eight hours the fire was allowed to burn out so that the chimney temperature was falling, and then all material on grates was weighed as ashes. The results were as follows:

"Duration of test, hours	8
Heating-surface, square feet	1,100
Grate-surface, square feet	33
Total coal fed to furnace, including equivalent of wood, lbs	1,880
Coal per hour, lbs	235
Coal per square foot of grate, per hour, lbs	7.1
Water evaporated at 185 lbs. pres. from 73° F., lbs.	17,143
Water per hour at 185 lbs. pres. from 73° F., lbs.	2,143
Horse-power with triple-expansion engine, at 15 lbs. per H.P	150
Temperature in chimney, deg. Fahr	443
Water evaporated in ash-pan, lbs	100
Air entering ash-pan by anemometer per lb. of coal, lbs	19
Draught-pressure, base of chimney, inches of water	0.25
Average boiler-pressure above atmosphere, lbs	185
Temperature of feed-water, deg. Fahr	73
Water evaporated per lb. of coal at 185 lbs. and 73°, lbs	9.12
Per cent of priming by Barrus superheating calorimeter	1.5
Water evaporated per lb. of coal from and at 212°, lbs	10.92
Water per lb. of combustible from and at 212°, lbs.	11.7
Per cent of ashes	7

"The total heat of combustion of the coal used for the above per cent of ashes was determined by a calorimeter test to be 13,900 British thermal units. The heat of the coal was therefore distributed as follows:

"Useful effect evaporating water, or efficiency	76%
Escaping through chimney	13%
Wasted in hot ashes	1.6%
Wasted evaporating water in ash-pan	0.3%
Lost by radiation, etc	9.1%
	100%

"The results are excellent, considering the exposed condition of the exterior of the boiler. The efficiency obtained even under these circumstances is above the average performance of good boilers.

"There were no special arrangements made for these tests: the boiler was wholly exposed to the atmosphere; the ends of the steam-drums, the return-pipes, the cross-pipes, and the water-drums were not lagged or protected from radiation in any way. The fireman had never had any experience with this type of boiler previous to these tests."

In a recent test carried out by Professor Denton, on one of these boilers having 1100 sq. ft. heating-surface, an evaporation of 8.5 lbs. of water into steam at 250 lbs. pressure per square inch was realized per square foot of heating-surface per hour, with only 2½″ air-pressure, the steam showing but 1½ per cent of moisture, from a feed-water temperature of 60 degrees Fahr., and a stack temperature of 520 degrees.

Another test made under very severe forced draught, namely, 12″ of air-pressure, showed an evaporation of 18.2 lbs. of water per square foot of heating-surface per hour into steam at 250 lbs. pressure, the steam at all times showing less than 2 per cent of moisture.

The object of this trial was not for the purpose of advocating any such rates of combustion, but of noting the action of the boiler as to any evil effects arising from such severe treatment. In practice a boiler may occasionally be driven to this extent if it lies within the power of the fan. The boiler showed no fatigue or effect whatever from this test, every joint remaining absolutely tight.

No account of the amount of coal burned was taken on this test, as it was made to show the action of the boiler under more severe treatment than it is likely to receive in the case of any very sudden demand for large quantities of steam.

Steam has been raised from cold water with a light wood fire within three minutes of lighting the same, and one hundred pounds pressure shown on the gauge in seven minutes.

The steam yacht "Norwood," which I designed and constructed in 1889, contained the first boiler of this type (see Fig. 7). It has been in use for three years, giving the utmost satisfaction, with forced draught at times equal to 10 inches of water, salt water having been largely used during this time, after which the tubes began to show evidence of pitting. Previous to this no leak of any kind or deterioration of the boiler in any part had appeared.

FIG. 7.

This boiler has just been replaced by one of the same type, with some later improvements. (See Fig. 8.)

The remarkable speed of the "Norwood" in the measured-mile trials on the Wonasquan Boat Club course, which was covered in 1 minute and 58 seconds, was undoubtedly largely due to the light weight and steaming capacity of the boiler.

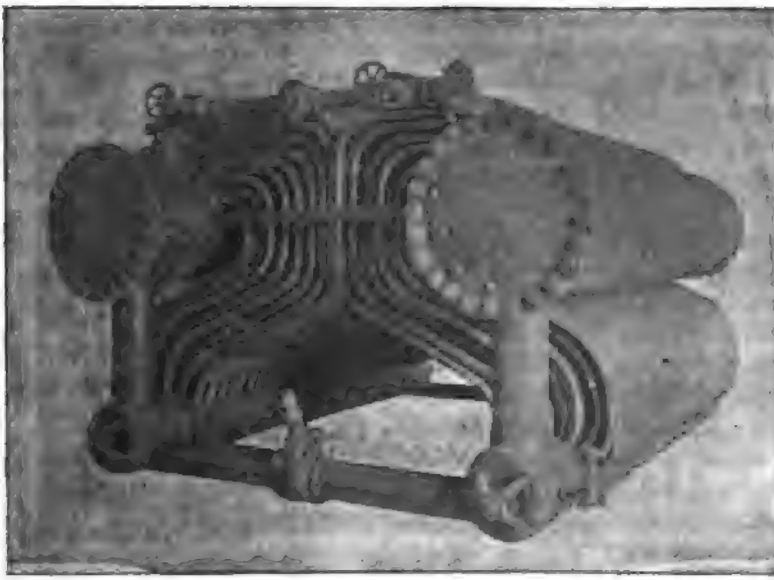


FIG. 8.

In concluding this paper the writer would state that he has tried to confine his remarks to the natural laws and principles involved in the mechanical construction, operation, and character of water-tube or tubulous boilers, rather than to make any direct comparisons, or criticisms on any particular boiler.

MR. E. E. ROBERTS:—Since the discussion of Water-tube Boilers at Chicago, in which I had the unexpected honor to participate, it has been suggested to me that a brief description of the Roberts boiler should be incorporated in the printed report of the Proceedings of that body, and I have therefore, at the request of Commodore George W. Melville, U. S. N. (the talented Chairman of Section G), endeavored to prepare the following brief paper.

The theoretical objections to the method of construction of this boiler, which were originally urged by competent engineers when it was first introduced to their notice, have, I am happy to say, been largely disproved by the practical performance of the five hundred and fifty boilers which have been constructed at the date of this description.

Probably the first criticism which will suggest itself to the intelligent mind is in regard to the abrupt bends and great aggregate length of each upflow coil, as compared with the diameter of the pipe from which it is constructed. I use the term "pipe" advisedly, for the reason that Americans at least distinguish between "pipe" and "tube," by the fact that the former is measured on its internal diameter, and the latter is recognized (as to size) by its external diameter. I am not, however, aware that the terms involve anything in regard to quality or the thickness of material, which might be the same in either. This criticism in regard to the upflow coils would probably extend to the assertion that the *apparently* excessive frictional resistance to the upward flow of the water would cause a break in the circulation, with the result of driving the water in both directions from a given heated point, where steam would be generated with a sufficient excess of pressure to prevent its return, and with the natural consequence of burning the exposed metal. In controversion of this criticism I can only allege the fact that it has been disproved by practice. I acknowledge that this practice has been demonstrated principally under natural draught only, but these boilers have also been used with forced draught and closed ash-pits, and, more frequently, with the exhaust in the smoke-stack under late and heavy release, while burning anthracite coal in some cases and bituminous in others. A fixed and steady water-line was shown in every instance, which would not have been the case had the circulation been impaired. I regret that I have no information in regard to the air-pressure used in the closed ash-pits, nor the amount of coal burned per square foot of grate. As previously explained in remarks during discussion, I have been heretofore too busily engaged in making this boiler a *commercial* success to give much attention to the collection of scientific data, which I would now be glad to present were it possible.

I have been allowed a patent (among others) covering a similar construction of boiler, in which the upflow section (or member) consisted of what might be called a "gang" of pipes set on an incline and connected with "headers" or "branch tees" at each end, one of these "headers" being connected by a pipe with one of the horizontal water-drums at the side of the fire (designated as a "side pipe"), and the other being similarly connected with the (upper) steam and water-drum. This method apparently reduces the resistance to flow, but has other objections, which in my opinion more than counterbalance this theoretical benefit. One objection is the decreased elasticity, with a consequent tendency to cause leaks

in joints; and another is the possibility of the greater part of the flow of water being conducted through some of the pipes to the exclusion of others, with a natural tendency of the latter to become stopped with foreign matter, owing to sluggish flow. This is not so liable to happen in the original (and present) construction, in which the circulation is continuous from end to end of the coil, and sweeping in its effect.

It is possible that boilers of the "gang section" type may have to be adopted if used with a considerable air-pressure; but my experience so far does not prove this, as the very efficient natural circulation in the present type of construction has heretofore met all the requirements, and is undoubtedly caused largely by the fact that the height of the upflow and downflow columns are equal, and the steam-bearing water, consequently, does not have to be raised above the height of the downflow columns.

Theoretical objections have been urged against the superheating coils in the Roberts boiler on account of the apparent "wire-drawing" of the steam between the boiler proper and the engine, caused by the length and bends of the superheating coils. I have never had an opportunity of ascertaining the difference of pressure, if any, between the boiler and the cylinders; but I am under the impression that the large area of cross-section of *both* superheating coils, compared with the main steam-pipe, obviates this objection to a considerable extent, especially in view of the constant evaporation of the moisture in the steam, and its consequent expansion in bulk as it travels from the spray-pipe to the outlet from the superheating coils. It will be noted that the steam in its course continually comes in contact with hotter surfaces nearer the fire. The spray-pipe, from which both the superheating coils take their steam, extends from head to head of the drum, and is drilled full of holes *in the centre of its length only*, so that pitching of the vessel, with the resulting dash of water against the heads, has no tendency to throw water through these holes. This spray-pipe lies close to the top of the shell of the drum, with the holes on the upper side. I have never had any complaints as to the boiler giving wet steam, but *have* had complaints, in a few instances, of the steam being too dry. This has always been remedied by carrying the water higher in the boiler, and the steam can be made as dry or as wet as required by simply altering the water-level.

The feed-water heating coils lie on each side of the drum, between the boiler proper and the smoke-stack, and thus extract a large part of the heat which has passed through the boiler without being thoroughly utilized in making steam. They are thoroughly

protected from overheating, if empty at any time, by the fact that much of the heat is absorbed from the fire before reaching them. As in the case of the steam superheating coils, it will be seen that the coldest water, which enters at the top of the coils, comes in contact with the coolest products of combustion, and as the feed-water is forced downward it becomes heated and comes continuously in contact with still hotter surfaces till it reaches the bottom coil, from which it is delivered through the heads of the drum at a point above the water-line. It is delivered at this point for the reason that, with a slow feed, much steam may be delivered with the water, and it is desirable that this should be separated in the drum before the water drops to the normal water-line in the boiler.

It is true that these boilers do not contain as much heating-surface per square foot of grate as some other types, but the proof of efficiency is the temperature of the smoke-stack, and this peculiar arrangement of construction gives a low smoke-stack temperature. One reason why the ratio of the heating to grate surface is not so great in these boilers as in some others is that the comparatively small diameter of the lower water-drums (or side pipes) allows a greater grate-surface than in most other types occupying an equal space and having equal heating-surface, with the result that a slower combustion on a greater area of grate gives the same amount of steam with a greater economy of fuel. It has been found in practice, for this reason, that a Roberts boiler occupying a given space will give sufficient steam with natural draught, while another boiler with less grate-surface would require forced draught. The weights of the different sizes of Roberts boilers have not been accurately determined, but a boiler occupying a space of 7 feet in width by 8 feet in length, by 6 feet 2 inches in height, and having 35.33 square feet of grate and 1125 square feet of heating-surface, will weigh 13,000 lbs., including all fire-brick linings and grate-bars. Soot and ashes are removed from all the heating-surface by means of a jet of steam inserted through the furnace-doors or through hand-holes in the jacket. The rectangular shape of this boiler enables it to fill the available space with greater grate and heating surface than if it were circular in form. Many of these boilers have been built to occupy the available space in vessels which have previously been fitted with other boilers, and some of them have even been built much wider than their length.

I have reason to believe that I was the first inventor of boilers involving an upper steam and water drum and two lower water-drums, at each side of the fire, connected by downflow pipes and

by a large number of upflow pipes, or coils, which latter constitute the greater part of the heating-surface.

A reference to Fig. 9 shows the boiler "in frame," and before upflow coils, feed-water heating coils, and superheating coils have been added. It also shows the sediment pockets which trap all the sediment coming down through the downflow system, from

FIG. 9.

which it is discharged by a blow-cock attached to each pocket. The downflow pipes are made angular for boilers to be used in vessels carrying sail, or which are liable to have a "list" from any other cause. This is to avoid the possibility of any part of the downflow system being raised above the water-line of the boiler.

Fig. 10

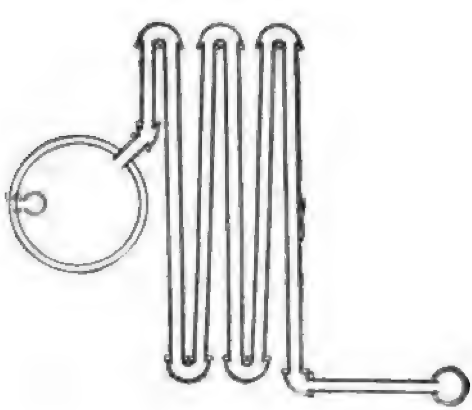


Fig. 10 shows a similar cut with only two upflow coils inserted, so that the view will not be obstructed. An annex is added to this cut showing a section through one side pipe, the drum, and an upflow coil. It will be noticed that this latter coil has a slight "pitch," as constructed for the larger sizes of boilers, and as explained in remarks before the International Congress, printed elsewhere.

Fig. 11.

Fig. 11 shows all the upflow coils inserted.

Fig. 12 shows the boiler complete with feed-coils and superheating coils, but without the jacket. I regret that this cut is defective in regard to the head of the drum, but pressure of time will not allow of a better cut being supplied. The ring and link

around the drum is for attachment, through the smoke-stack aperture, of a tackle for facility in hoisting small boilers.

Fig. 13 includes the sectional jacket or casing, which is filled with magnesia blocks of a thickness varying according to the size of the boiler. This casing can be taken off by removing it entirely or in sections. In case the boiler is so enclosed in the vessel that

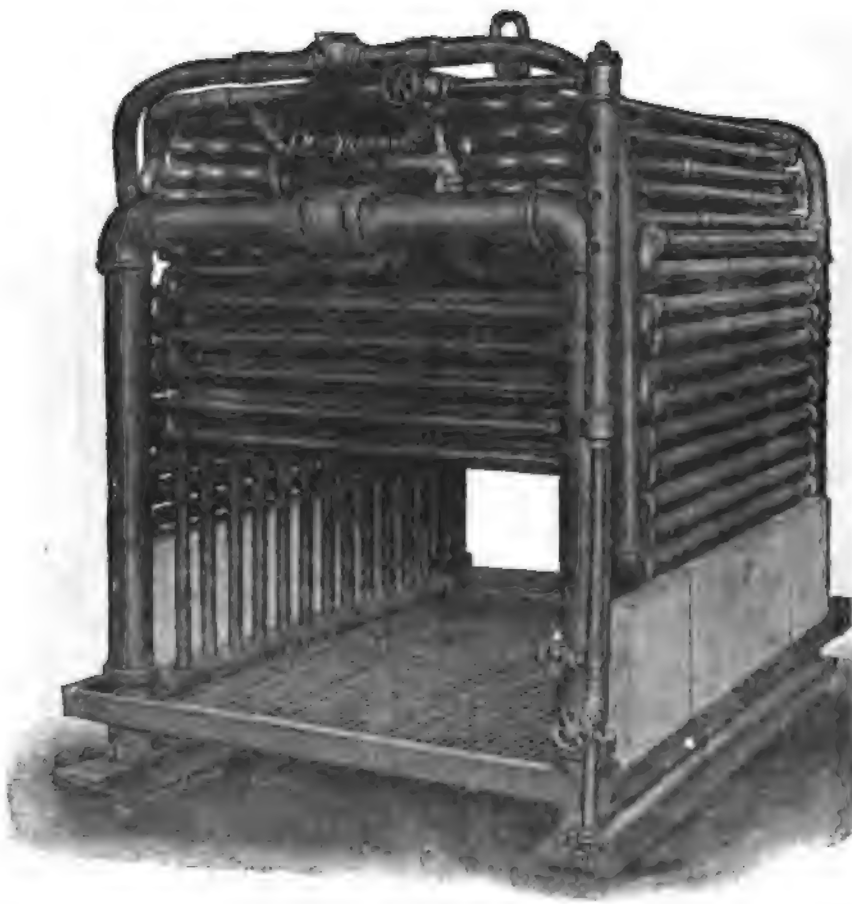


FIG. 12.

the bolts on the rear of the jacket cannot be readily reached, bolts are used extending *through* the double jacket to the front, with nuts on the front ends only. There are no packed joints in the boiler. The holes in the drum and in the side pipes are all tapped left-handed, so that any section can be removed without removing any other section.

In use, the boiler is filled to the level of the second gauge-cock, so that the whole downflow system and the lower part of the drum contains water. When the fire is started the water is rarefied in the upflow coils much faster than in the downflow pipes, both on account of its greater subdivision in the small pipes, and also on account of the upflow coils being in a position where they absorb a

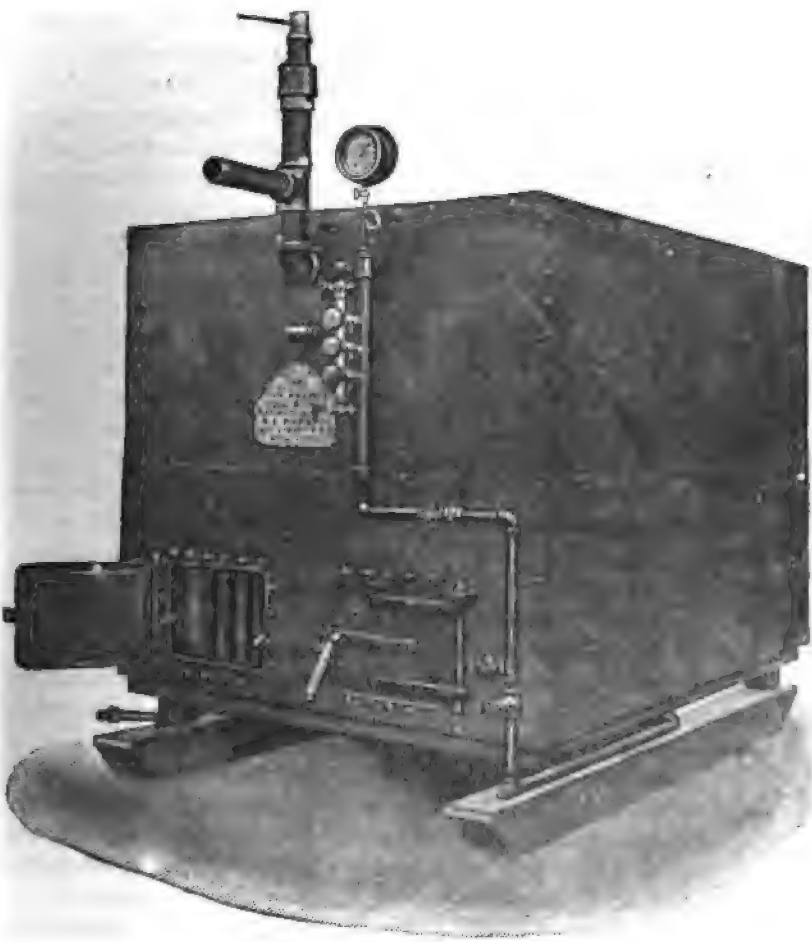


FIG. 18.

much greater amount of heat. The result is that the water at once commences to rise in the small upflow pipes, and to fall in the large downflow pipes. As soon as steam-bubbles commence to form, this movement of the water is greatly accelerated. The upflow coils then begin to throw fountains of water mixed with steam-

bubbles into the drum on a line with the water-level. The steam-bubbles break, the steam escapes into the spray-pipe, and their watery envelopes, and other solid water, flow out of each end of the drum into the downflow pipes, and thence, after dropping the sediment into the sediment pockets, into the side pipes, from which it is forced through the upflow coils again by reason of the superior weight of the water in the downflow pipes.

In regard to repairs, I would say that an upflow coil has been removed from the centre of one of these boilers, and a new one replaced and made tight, in twenty-two minutes by the watch. This boiler was 5 feet wide by 7 feet long by 5 feet 2 inches in height, and had 21 square feet of grate-surface and 698 square feet of heating-surface. The method of operation was as follows: The smoke stack guys were released, and the smoke-stack lifted out of the stuffing-box in the casing. The upper section of the casing (or cover) was raised 3 inches, and pipe-rollers inserted under it, upon which it was rolled on an incline into the fire-room. One of the feed-coils was then disconnected and lifted over on the other side of the boiler. A man then disconnected the right and left nipple connecting the upflow coil with the drum. Another man, in the furnace, disconnected the coil in the same way from the side pipe. The grates had been previously removed, and the coil was dropped into the ash-pit and pulled out from under the boiler. The new coil was inserted and connected in the same way. The holes in the drum and side pipes could have been *plugged* with less labor if this had been preferred. All joints in the boiler have right-hand threads excepting those at both ends of each upflow coil, those on one end of each downflow pipe, and those at each end of the feed-water heating coils and steam superheating coils. There is no cast iron used except for dead-plates and grates. Great variation in size and shape is allowable with few patterns.

MR. GEO. W. DICKIE:—The boiler-tests to which I referred in my remarks on page 43 were conducted at the instance of the Pacific Improvement Company, for the purpose of determining the best type of boiler to be employed in a large installation of power that they had in contemplation for electric-railway purposes.

The trials were conducted by Mr. W. R. Eckart, Consulting Engineer, San Francisco, with whom was associated Mr. John Wilson, the Engineer to the Pacific Improvement Company.

Through the kindness of Mr. Eckart we are enabled to give the results of this very interesting trial. These results possess great value from the fact that unusual precautions were taken and special devices used to insure accurate results.

The three types of boilers tested are shown in the accompanying illustration.

The Elephant boiler was taken to represent the best type of fire-tube boiler in use on the Pacific coast, one set of the boilers in use at the Union Iron Works being taken.

The Heine boiler represents a water-tube boiler with a larger amount of water in the boiler and a larger water-surface than most types of the water-tubulars, one of the boilers in use at the San Francisco Gas Light Works being taken.

The Babcock and Wilcox boiler represents the water-tube boiler of a more pronounced type, one of the boilers at the Geary Street Railroad power-station being taken.

The boilers were all thoroughly cleaned inside and outside; all connections not needed in the test were broken and blanked. The steam-gauges, thermometers, pyrometers, and scales had all previously been compared with standards, and errors, if any, noted.

Fires had been going a sufficient time before the test to insure the boilers and settings being thoroughly heated, and every precaution was taken necessary to a careful and thorough test. The feed-water was measured in a tank which had been previously weighed, and was discharged into a second tank, from which it was pumped into the boiler. The temperature and time of discharge were taken by an attendant. The coal was weighed by barrow-loads of uniform weight, the time being taken by an attendant. A series of records were produced automatically by electro-magnetic pointers recording on a piece of smoked paper fastened to a drum that was revolved by clockwork.

One set of wires from the magnet led to the scales, where the attendant made contact when recording the weight and time on his tub.

The other set of wires went to and were connected with the cock drawing water from the measuring-tank, so that each load of coal leaving the scales was recorded on the time-drum, and each tank of water, as well as the length of time required for discharge, was recorded. The centre time-scale was simply recorded by hand at the hourly periods.

The diagrams thus formed were a complete record of all data, and served as a check on the work of those weighing coal and measuring water.

Temperatures of feed-water and steam were read from thermometers placed in oil-baths in the steam and feed pipes, as close to the boiler as possible; that of the flue was taken by a pyrometer.

Readings of pressures and temperatures were taken every twenty minutes, and calorimetric tests of the steam made with a Carpenter separating calorimeter every hour. Samples of the coal were tested by a Thomson coal calorimeter, and were also dried, and the percentage of moisture obtained. All boilers were fitted with the same kind of rocking grates. At the commencement of the test fires were hauled and fresh ones started with wood and waste, which were charged as coal at $\frac{4}{10}$ their weight.

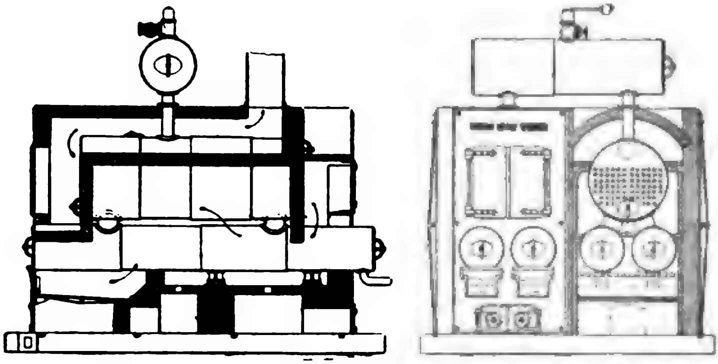
Steam-pressure and height of water in gauges were noted. At the close of test fires were allowed to burn low, the steam-pressure and water-level raised to the same places, and the fires hauled and charged as refuse.

TABULATED RESULTS ACCORDING TO FORMS NOS. 80-4 AND 80-5 OF THE U. S. NAVY DEPARTMENT.

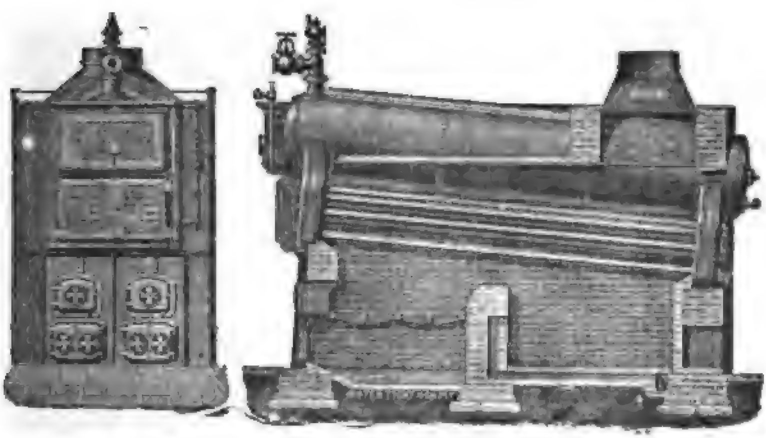
	B. and W.	Heine.	Union.
Average steam-pressure, absolute, p........	119.76	117.67	116.785
Average temperature of the feed-water t....	150.13	130.73	135.69
(a) Number of pounds of water vaporized, $W_1 \times Q$	135,832.35	95,446.14	168,441.57
(b) Number of pounds of water carried over with the steam, $W_1(1 - Q)$.............	1,818.50	674.02	1,191.33
Total heat of steam at pressure p....... ...	1,185.98	1,185.576	1,185.41
Total heat of water at temperature t_1.......	118.33	98.845	103.91
(c) Units of heat required to vaporize 1 lb. of water from temperature t and under pressure p..............	1,067.66	1,086.73	1,081.50
(c_1) Units of heat required to raise the temperature of 1 lb. of water from t_1 to the temperature due to the pressure p......	194.59	212.70	207.0
(d) Units of heat required to vaporize 1 lb. of water from and at a temperature of 212° and under atmospheric pressure....	965.7	965.7	965.7
Total heat required to vaporize the water $a \times c$.	145,022,766.8	103,794,183.7	182,169,557.9
Total heat required to raise the temperature of the water, $b \times c_1$....................	353,861.9	143,364.0	246,605.3
(e) Total heat obtained from the fuel as measured by the steam discharged......	145,376,628.7	103,867,547.8	182,416,163.3
(f) Units of heat obtained per pound of dry fuel....................................	6,254.9	7,341.83	7,355.63
(g) Units of heat obtained per pound of dry combustible.........	7,606.75	8753.83	9036.1
$\left(\frac{f}{c}\right)$ Potential evaporation per pound of fuel from a temperature t_1, and under a pressure p.............................	5.8565	6.7558	6.8013
$\left(\frac{g}{c}\right)$ Potential evaporation per pound of combustible from a temperature t_1, and under a pressure p...........	7.1246	8.0550	8.3551
$\left(\frac{f}{d}\right)$ Equivalent potential evaporation per pound of fuel from and at a temperature of 212° and under atmospheric pressure.	6.4770	7.6025	7.6168
$\left(\frac{g}{d}\right)$ Equivalent potential evaporation per pound of combustible from and at a temperature of 212°, and under atmospheric pressure.............	7.8769	9.0647	9.357
TOTAL QUANTITIES.			
Duration of test in hours....................	19.8633	19.9033	20.1
Wet fuel consumed......	23,760.85	14,577.8	25,761.13
Moisture in fuel	518.83	430.42	961.63
Refuse from fuel, in dry ashes, dust, and clinkers	4130.5	2282	4612
Combustible consumed.	19,111.52	11,865.38	20,187.51
Water fed to boiler by tank measurement W_1..................	137,650.85	96,120.16	169,632.9
Per cent of the fuel in dry refuse, etc.......	17.43	15.73	17.93

TABULATED RESULTS ACCORDING TO FORMS NOS. 80-4 AND 80-5 OF THE U. S. NAVY DEPARTMENT—(*Continued*).

	B. and W.		Heine.		Union.	
Average Quantities.						
Temperature of feed-water t_1	150.129°		180.728°		185.69°	
Temperature of steam, by thermometer	340.39° / 331.29°		343.48° / 339.65°		339.89 / 331.96°	
Temperature of uptake	510.70°		569.48°		458.89°	
Temperature of atmosphere	64°		62°		53°	
Temperature of fire-room	82°		71.22°		69.1°	
Barometer in inches of mercury	29.78		29.968		30.061	
Pressure of steam at boiler, in pounds per square inch, above a perfect vacuum, 14.62 / 14.76 / 14.71 + pressure by gauge in pounds p.	119.76		117.673		116.785	
	Dry Fuel.	Combustible.	Dry Fuel.	Combustible.	Dry Fuel.	Combustible.
Rates of Combustion.						
Amount consumed per hour, dry	1,168.92	961.184	710.8	596.15	1,233.8	1,004.35
Amount consumed per hour per square foot of grate-surface	31.18	25.64	34.3	28.77	20.57	16.74
Amount consumed per hour per square foot of heating-surface, exterior	....	....	....	....	....	....
	Per Lb. of Fuel.	Per Lb. of Comb.	Per Lb. of Fuel.	Per Lb. of Comb.	Per Lb. of Fuel.	Per Lb. of Comb.
Vaporization in Pounds of Water.						
Apparent evaporation, by tank measurement, from a temperature t and under pressure p	5.922	7.2025	6.794	8.1008	6.840	8.408
Equivalent apparent evaporation from and at 212° and under atmospheric pressure	6.5477	7.963	7.645	9.116	8.201	10.075
Actual evaporation into steam of quality Q from temperature t_1 and under pressure p	5.848	7.1073	6.746	8.044	6.798	8.3438
Equivalent actual evaporation from and at 212° and under atmospheric pressure	6.4613	7.8577	7.592	9.0522	7.6065	9.3443
Potential evaporation, or evaporation had all the heat obtained from fuel been utilized in converting the water in the boiler into dry saturated steam from a temperature t_1 and under a pressure p	5.8585	7.1246	6.7558	8.0550	6.8013	8.3551
Equivalent potential evaporation from and at 212° and under atmospheric pressure	6.477	7.8769	7.6035	9.0647	7.6163	9.3570



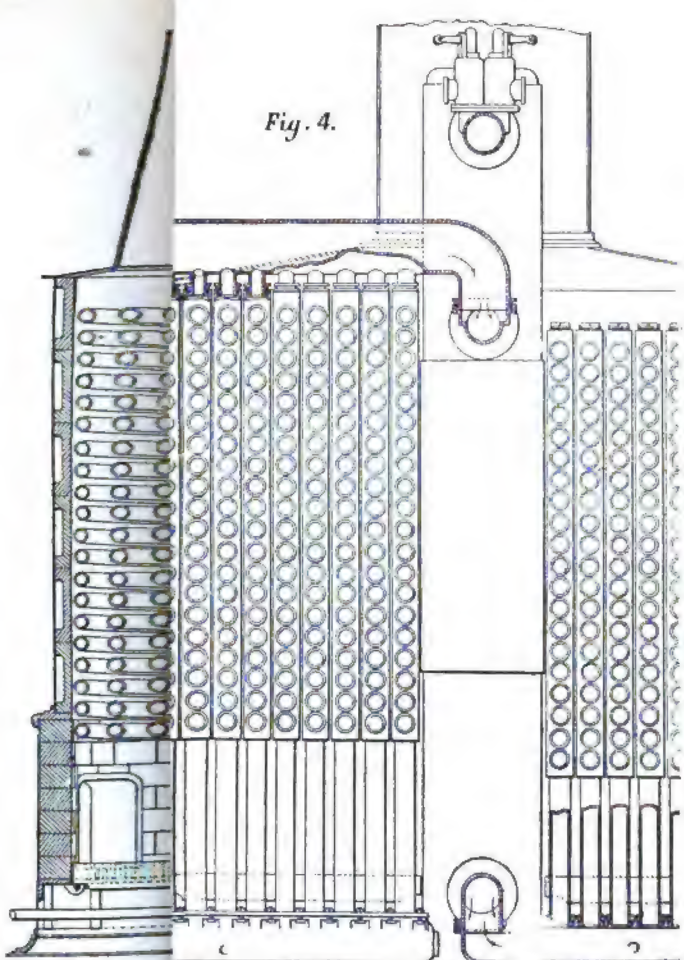
ELEPHANT BOILER.



THE HEINE SAFETY BOILER.

THE BABCOCK & WILCOX BOILER.

Fig. 4.



BOILER

Made for

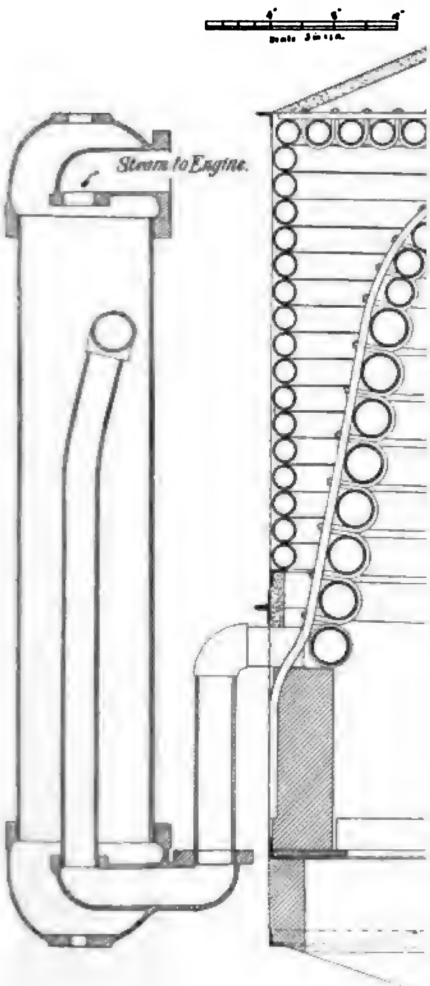
VEDETTE BOATS Nos

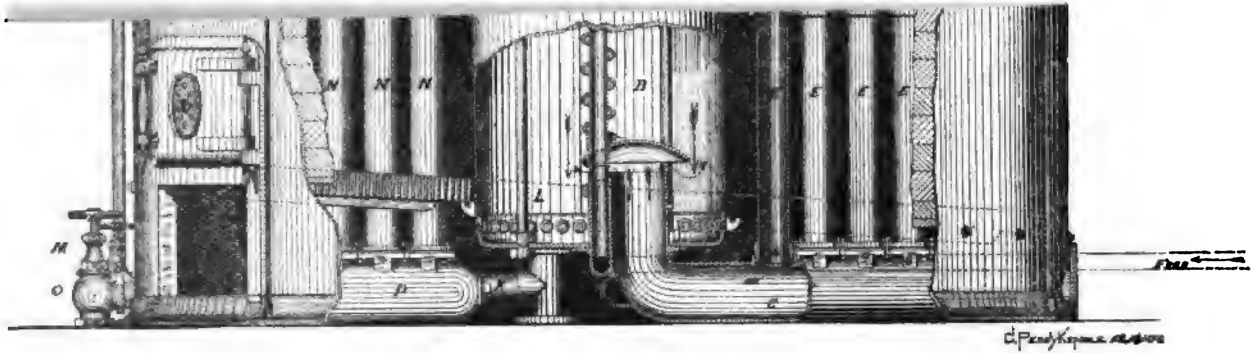
Built By The

Herreshoff Manufacturing (

Bristol, R.I. June 26

1882





WARD'S STEAM GENERATOR.

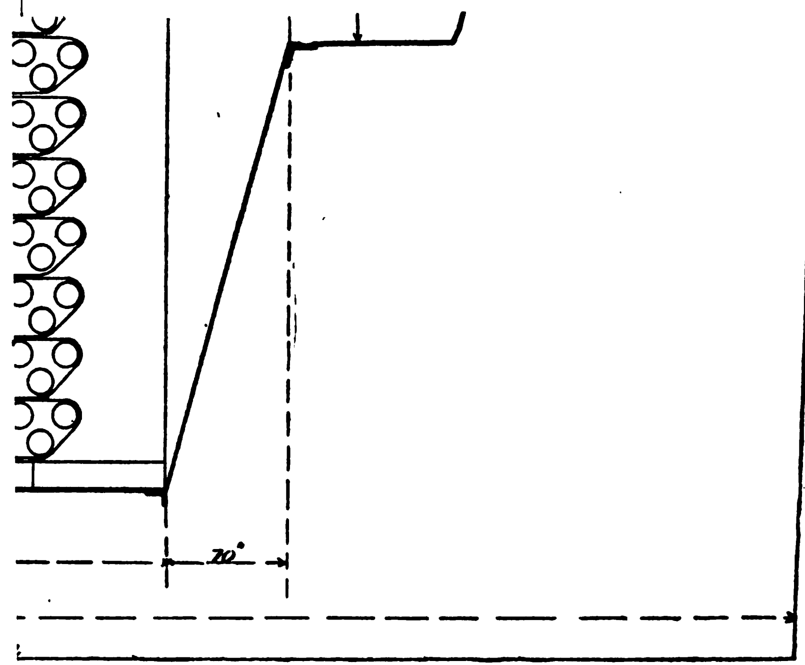
TOTAL { HEATING SURFACE 1881 / GRATE " " 42 } SQUARE FEET.

No. 24.

PLATE IV.

PLATE V.

Ward Boiler for U. S. S. Monterey.


70°

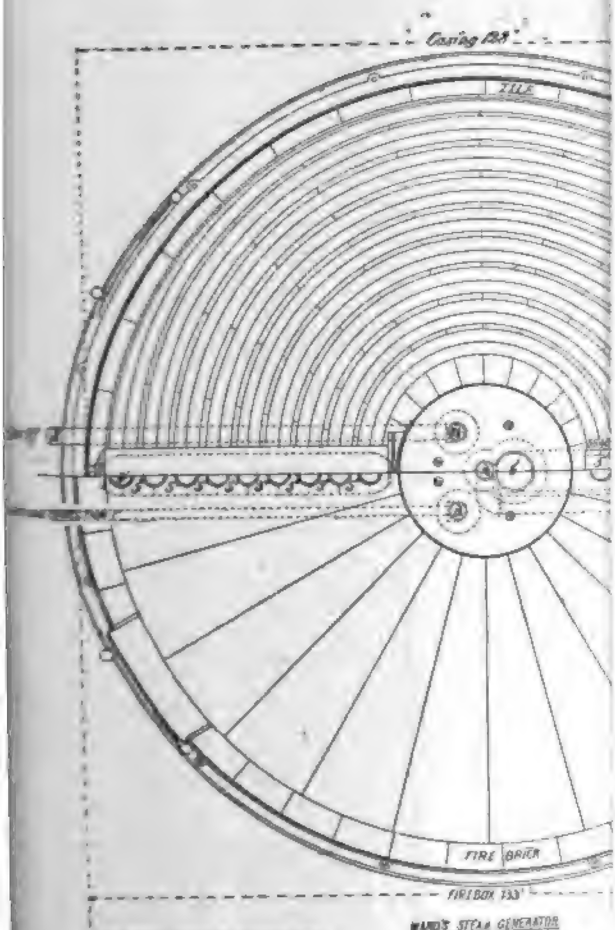
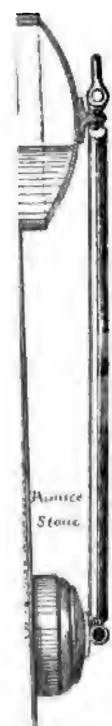
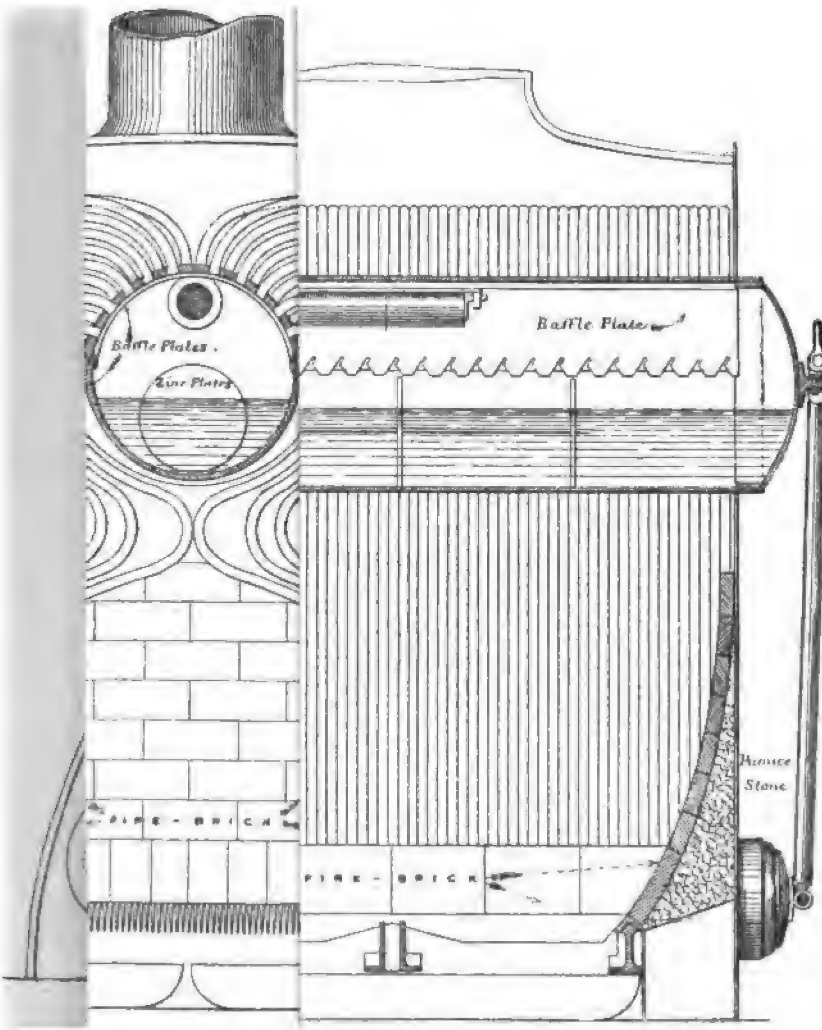


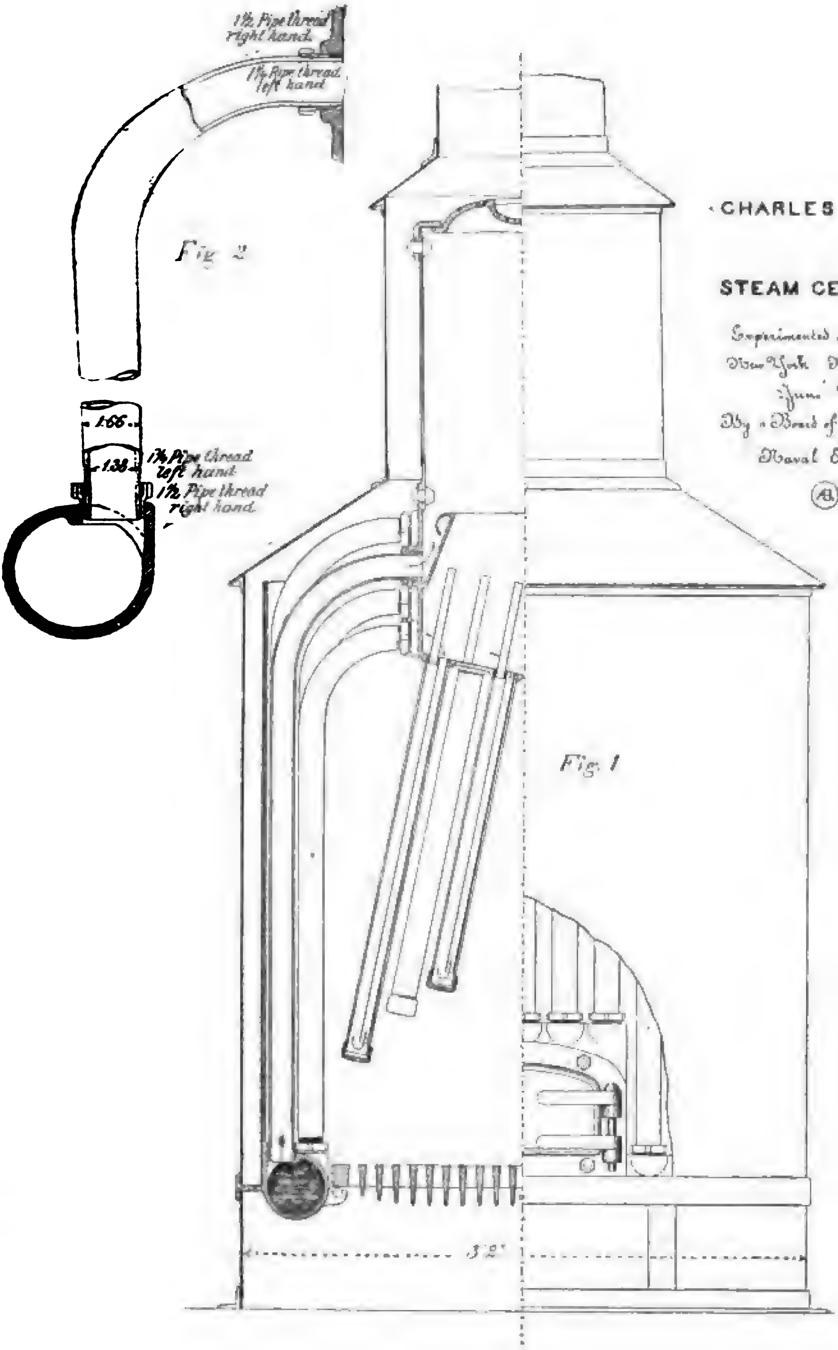
PLATE VII.





T " W A T

PLATE VIII.



CHARLES E WARD'S

STEAM CENERATOR.

Experimented with in the New York Navy Yard. June 1884

By a Board of United States Naval Engineers

PLATE IX.

PLATE X.
ROBERTS PIPE-BOILER.

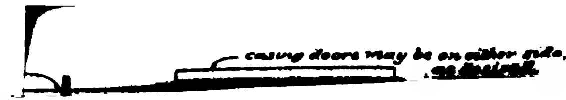
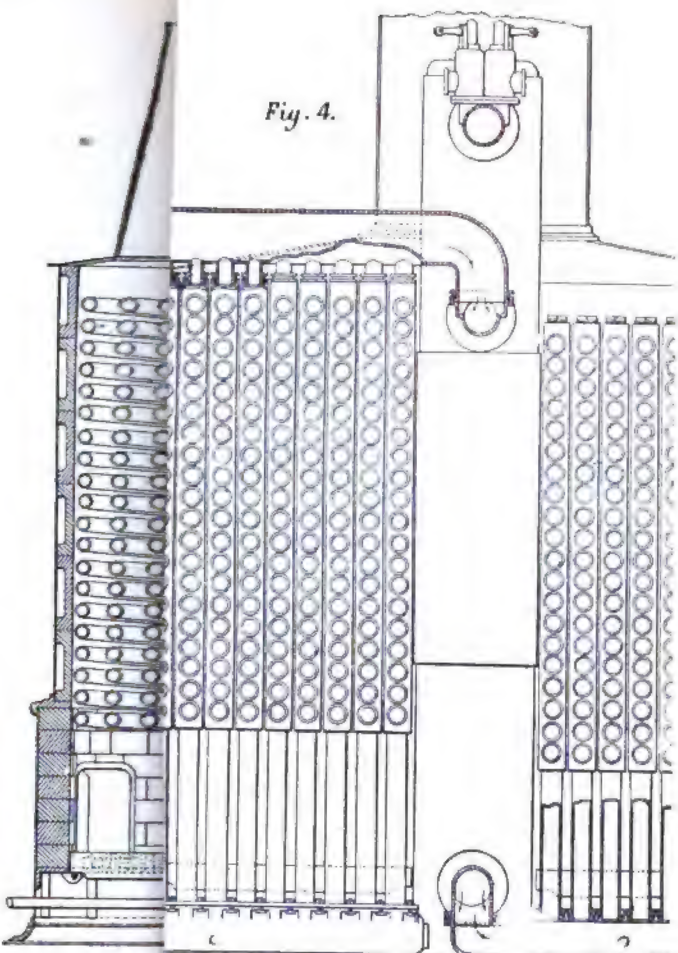
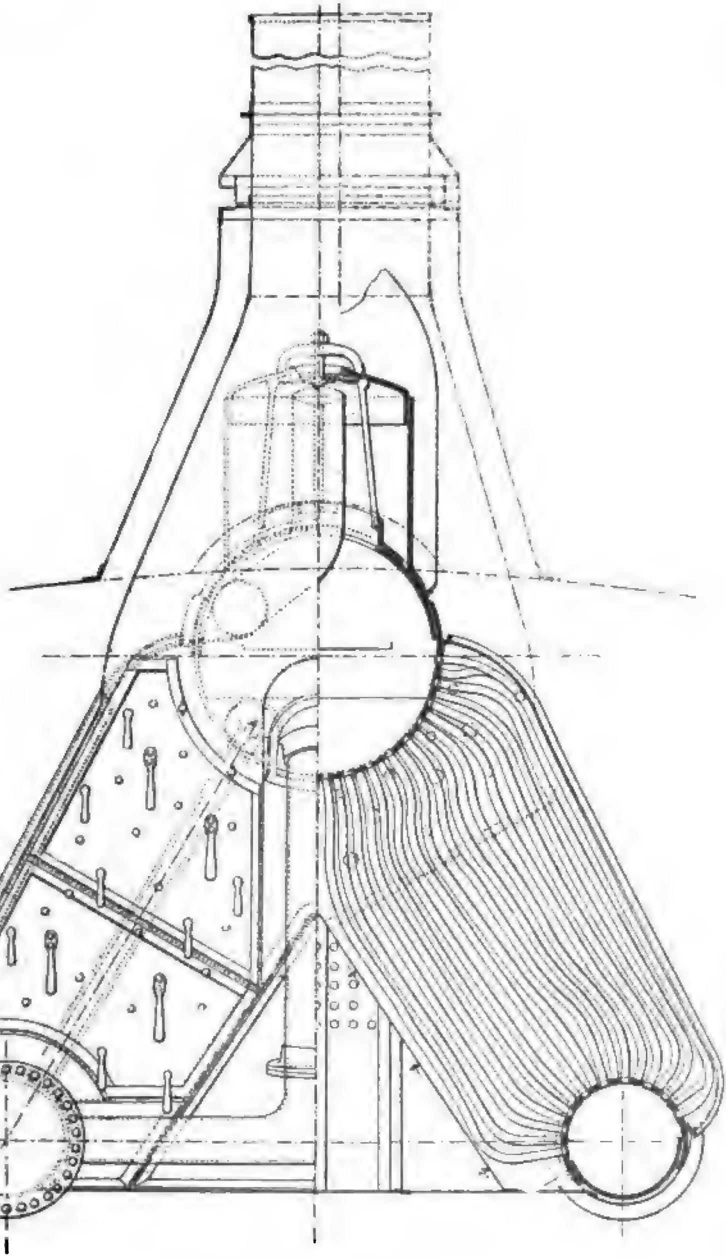

casing doors may be on either side,
as desired.

Fig. 4.





NORMAND'S WATER-TUBE BOILER

PLATE XVI.

PLATE XVII.

WARD'S NAVAL BOILER.

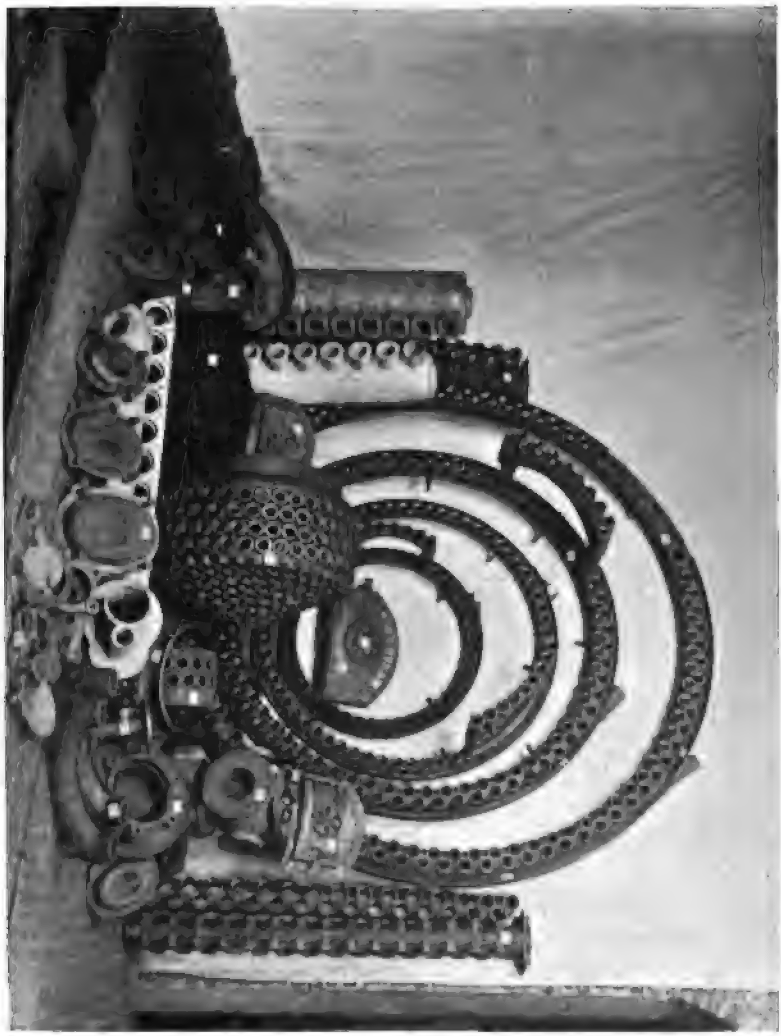
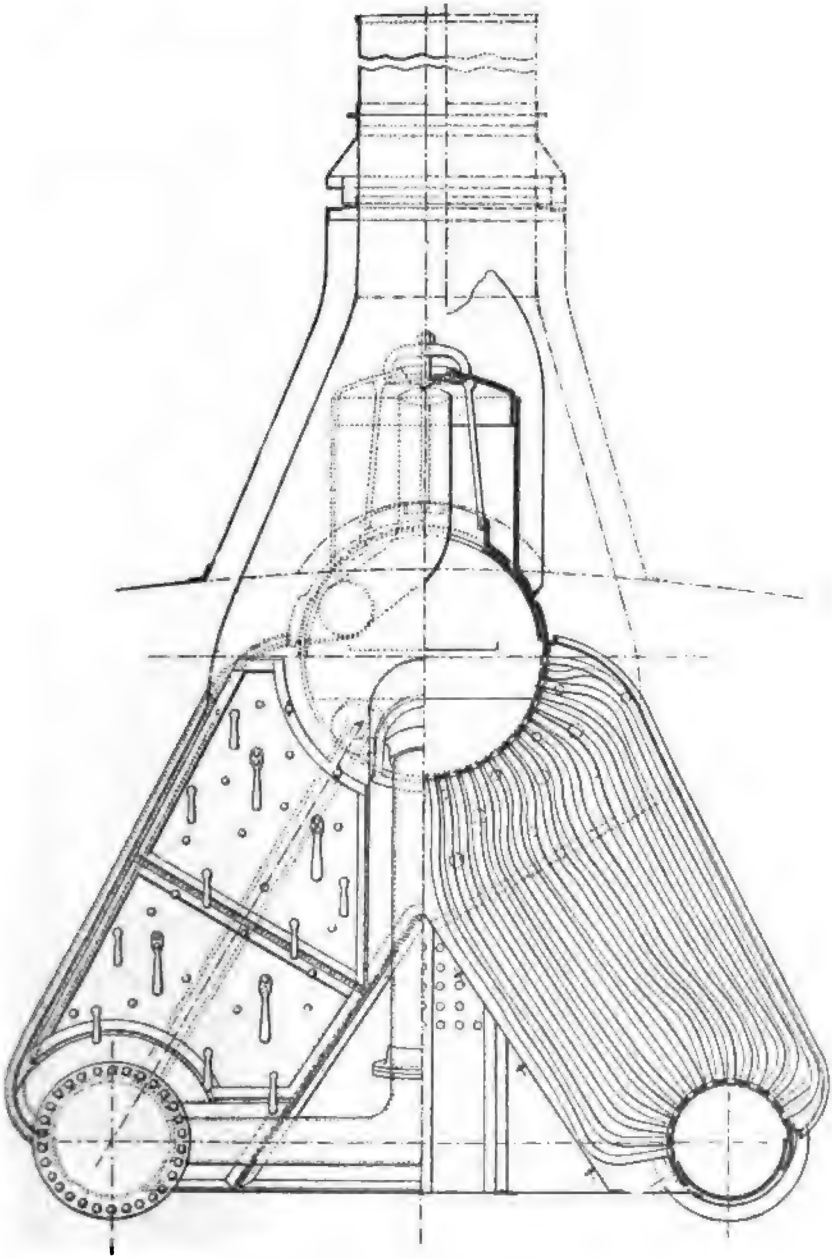


PLATE XVIII.

Steel Castings for Ward's Boilers.



NORMAND'S WATER-TUBE BOILER

PLATE XVI.

PLATE XVII.

WARD'S NAVAL BOILER.

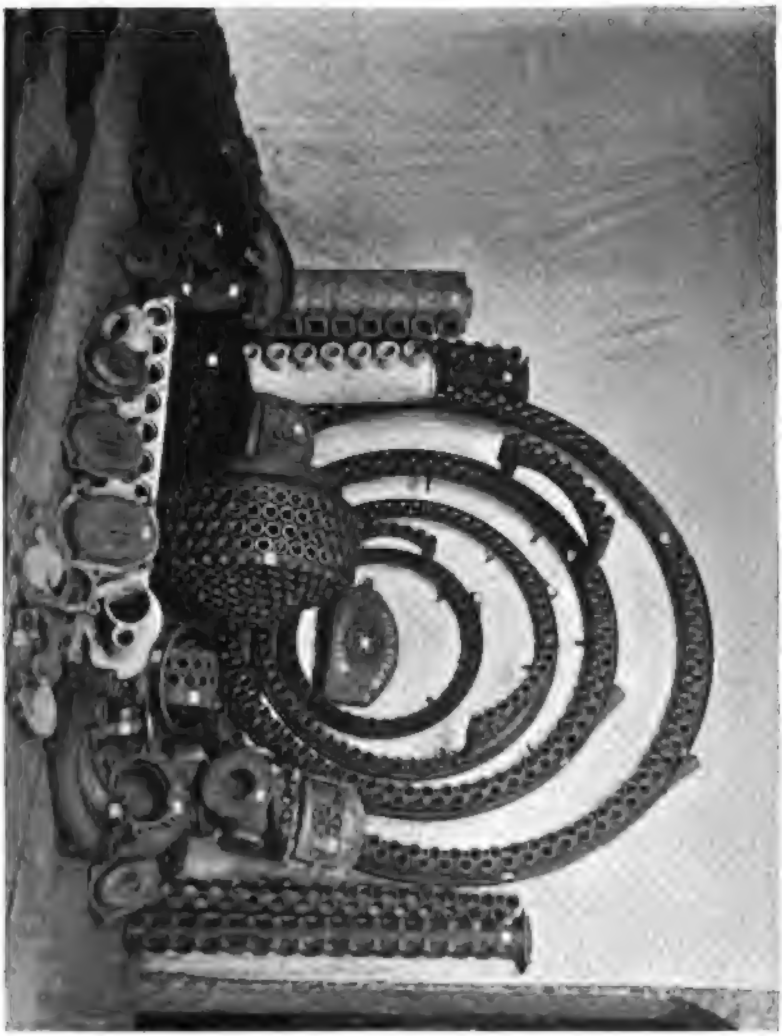


PLATE XVIII.

STEEL CASTINGS FOR WARD'S BOILERS.

XXVII.

THE NECESSITY OF A STANDARD INDICATOR AS SHOWN BY THE RESULTS OF TESTS MADE WITH DIFFERENT INSTRUMENTS IN MEASURING THE SAME POWER.

BY DAVID SMITH,

Chief Engineer, U. S. Navy.

WHEN we consider the numerous and varied uses to which steam is applied at the present day, the vast amount of capital invested in its production and utilization, and the high premiums that in many cases are paid for each additional horse-power over the amount contracted for, the necessity for an accurate and reliable measure of the power exerted by the steam is apparent to all.

It is needless to say that the instrument universally used in measuring the power developed by steam in the engine is the indicator, and that its indications are believed and accepted by the engineering world in general with the implicit faith and confidence of the Christian in the teachings of Holy Writ.

Under these circumstances, for any one to question its accuracy is to lay himself open to the charge of gross heresy, and render himself liable to suffer the penalty declared against the doubter.

But disregarding all personal considerations, and in the interest of truth and justice, I earnestly call the attention of this assembly to the results of certain tests made by me at different times during the past nineteen (19) years, which certainly cast very serious doubts upon the accuracy of the indicator, if they do not furnish absolute proof of its total unreliability as an instrument to measure power.

My attention was first directed to this subject in 1874,

while testing a number of indicators at the Navy Yard, Washington, D. C., in order to be able to select one that would practically agree with an indicator, guaranteed as to accuracy by the maker, that had been made and furnished expressly for use in a series of tests on a small compound engine which I was about to conduct.

There were fifteen (15) indicators from which to make the selection, representing four different makes or types; all of them had been more or less used, but all were deemed good and serviceable instruments, and were held in store ready to be issued to vessels upon requisition.

A cold hydrostatic pressure, in conjunction with the mercury-column, was used in making the scales of the spring's tension,* from the zero (0) or atmospheric line up to the limit of the pressure of the spring, by noting each successive five-pound interval as indicated on the column. In these and all subsequent tests, three tension scales were made with each instrument, in order to guard against errors in observation.

Upon making the comparisons, it was found that the special or standard indicator practically agreed with the scale furnished with the instrument, and that the others varied from their scales from 1.5 to 7.5 pounds, or, in percentage, from 2.5 to 12.5 per cent, some being above and others below their scales, and none of them agreeing with the standard or with each other.

These results were a great surprise and a revelation to one who had been a true believer in the indicator up to that time and had accepted its indications with perfect confidence.

Reflection suggested the question: How will these indicators vary in their normal working condition if they vary so much when cold?

Natural curiosity and the possibility of obtaining another indicator for the work in hand alike demanded an answer to this question.

It took but little time and involved but a trifling expense to fit up a steam-pipe suitable for testing two indicators at a

---

* The word "tension" in this paper is used to express the force in pounds that is applied to compress or extend the spring, and the "scale of tension" is the scale of the measure of the compression or extension of the spring by regular increments of force.

time, under a steam-pressure that could be regulated at will, and provided with a steam-gauge that agreed with the mercury column to record the pressures.

Some preliminary tests showed that the friction of the indicator was an important factor in obtaining a true scale of the tension of its spring.

The method of making the scales when the instrument was heated, which will be termed the hot scales of tension, was briefly as follows:

The indicator being fitted as for taking a diagram, was well heated by steam of a pressure up to the limit of the spring, and a vertical line was drawn with the pencil of the instrument up to the limit of pressure to serve as a line of measures for the scale; the steam was then discharged from the pipe and the indicator-cock closed; the piston was then pushed down by hand and allowed to return slowly in order to oppose the friction to the upward movement of the piston, before drawing the atmospheric line.

After this line was drawn, the cock was opened, steam admitted to the pipe, and the pressure allowed to rise slowly until the first five-pound interval as indicated on the gauge was reached, when a short dash was made. A similar dash was made at each successive five-pound interval up to the limit of pressure, thus completing the up-scale.

Before beginning the down-scale the steam was allowed to rise slightly above the pressure to be first recorded, in order to oppose the friction to the downward movement of the piston; then the pressure was allowed to fall slowly, and at each five-pound interval a short dash was made, as in making the up-scales.

During the time these scales were being made, the steam-gauge was gently tapped with the finger, in order to avoid any errors arising from the "hanging" of the gauge.

The up-scales were a measure of the spring's tension minus the friction of the indicator, and the down-scales were a measure of the tension plus the friction; the true scale of tension of the spring lay somewhere between that of the up- and down-scales. It was assumed that the friction would be the same at each point of the stroke, whichever way the piston was moving, as there was no means at hand for determining if there was any difference. The true scale of tension of the

springs was, therefore, taken as the arithmetical mean of the two scales.

These being the first scales which, to my knowledge, had ever been made while the indicators were heated to the temperature due to their normal work, they had a special interest, and were studied and measured with great care. Marked irregularities, varying from zero (0) to forty (40) per cent, were discovered in the lengths of the intervals at different parts of the same scale, which did not appear in the scales made in the cold tests.

The test of each instrument showed its spring to have its own strong and weak points; and repeated tests not only confirmed this, but also showed that they recurred in a given spring at the same intervals of pressure, although their positions in the different springs varied greatly.

By substituting different springs, it was seen that the irregularities were due to some physical characteristic of the material of the spring, and not to irregularities in the bore of the instrument, as was at first supposed.

Upon making a comparison of these empirical scales with the scales furnished with the instruments, none of them were found to agree. The hot scale of the standard indicator at a pressure of 60 pounds per gauge measured 61½ pounds by the scale of the instrument, and those of the other indicators varied from their scales from 1.5 to 7.5 pounds.

Upon measuring, with the scale furnished with the respective indicators, the total lengths of the scales made under the hot and the cold tests, each of the hot scales was found to be longer by an amount varying, in the different scales, from 1.5 to 3 pounds; or, in other words, all of the springs had been weakened by the heat, due to the pressure up to which they were tested, to an extent varying from 2.5 to 5 per cent.

CONCLUSIONS.

The conclusions drawn from these two series of tests were the following:

First. That all indicators are not correct, if the tension of the spring is taken as the standard.

Second. That a cold hydrostatic pressure is not a true test of the tension of the spring of an indicator when in its normal working condition.

Third. That the scale of equal parts furnished with the indicator is not a measure of the tension of the spring when heated.

Fourth. That the true scale of a spring's tension is a scale of unequal parts, the irregularities depending upon the physical characteristics of the material of the spring.

Fifth. That all springs are sensibly weakened by the heat due to pressure of the steam under which they are tested.

Dynamic Tests.

After the first series of tests on the compound engine was begun and everything was found to be in good running order, advantage was taken of the intervals between taking diagrams with the standard indicator to obtain a similar set taken with another instrument, when the engine was developing the same power, which was assured by observation of the weight sustained by the dynamometer that had been provided to measure the useful power of the engine.

The indicator, whose hot scale was found to correspond the nearest with that of the standard, was tested first, then the next nearest, etc., until all were tested.

Three sets of cards taken from both ends of each cylinder (in all twelve single-power diagrams) completed the dynamical test of each instrument.

The mean pressures were obtained by measuring the diagrams with a paper scale made by dividing the five-pound intervals of the hot scale of each indicator, irrespective of their lengths, into five (5) equal parts. The power was computed from the revolutions and mean pressure in the usual manner.

Upon comparing the power of the twelve diagrams taken by each instrument with that of a like number of corresponding diagrams taken by the standard, none of them were found to agree with the standard or with each other. The fourteen (14) first tested varied from the standard in their measures of the power from 3.5 to 7.5 per cent, and the fifteenth and last instrument tested differed from the standard in its measure by only one-half of one per cent.

This was surprising, as the hot and cold tests had shown that the tension of its spring was too stiff as compared with the standard by 10 and 12¼ per cent respectively, while its

measure of the power was one half of one per cent in *excess* of that of the standard.

For some time this anomaly could not be explained, but reflection suggested that the weights of the moving parts of the instrument might be the cause, as they were more than double those of the standard. To settle all doubt in the case, two sets of diagrams were taken with both instruments at 40 and at 64 revolutions, and the measure of the power of the indicator with the heavy moving parts and stiff spring fell below that of the standard, in the first instance 7.5 per cent and in the second about 4 per cent; while, at 83 revolutions, in the course of the tests, its measure of the power was again one-half of one per cent greater than that of the standard.

CONCLUSIONS.

The conclusions drawn from the results of the dynamic tests were as follows, namely:

First. That the tension of the spring of an indicator is not a reliable test of its measure of the power.

Second. That the weight of the moving parts of an indicator affects its measure of the power.

Third. That the speed of the engine affects the measure of the power of an indicator, and, other things being equal, the higher the speed the greater will be its error in the measure of the power.

SECOND SET OF TESTS.

In 1884, at the Navy Yard, Washington, D. C., I was appointed senior member of a Board to test and report upon a new and improved indicator.

Comparative tests were made between it and an indicator of another make, which was regarded as being a very superior and reliable instrument.

After the above tests had been nearly completed, another and an improved indicator of the latter make was submitted to the Board for tests and report.

For convenience of reference, and also to avoid the appearance of favoring one make of instrument more than another, these indicators will be designated as *A*, *B*, and *C*, respectively.

A and *B* were fitted with 40-pound springs, and *C* with a

50-pound spring. When tested with a cold pressure, all three of the springs practically agreed with the mercury column.

In the hot tests, it was found that the irregularities in the scales of *A* and *C* were about the same, while those of *B* were greater; that the friction was nearly the same in all three instruments; that the scales of *A*, *B*, and *C* had been lengthened 1.5, 3, and 4 pounds, respectively, by the heat due to the pressure of 70 pounds per gauge, at which they were tested.

Dynamic Tests.

In the absence of a dynamometer to assure the development of the same power, the following plan was devised to obtain diagrams with two indicators at the same time, from the same end of the cylinder:

The nipple for attaching an indicator to a launch engine was removed, and a T substituted in its place; into the T were screwed two short pieces of pipe of equal diameters and lengths, terminating in right-angle bends fitted with suitable nipples for attaching two indicators in a vertical position, as near together as they could conveniently be secured in place; the guide pulleys of the two indicators were brought together over the lever giving motion to the paper drums, and the arms were clamped in place; the drum cords of the two instruments were tied together in a long loop, and a single cord connected the loop to the lever, thus giving coincident motion to the two drums.

By this arrangement, a single operator, after a little practice, could take simultaneous cards by using both hands, with the two instruments, at any required speed of the engine.

In these and all subsequent dynamic tests, the indicators were interchanged, one half of the diagrams being taken from each pipe by each indicator in order to eliminate any error that might arise from differences in the flow of the steam in the two branch pipes.

The mean pressure of forty (40) diagrams as measured by the hot scales of the spring's tension, taken by

A	35.935	lbs.
B	34.972	"
Difference	0.963	"

Excess of mean pressure of *A* over that of *B*, 2.75 per cent.

The mean pressure of twenty (20) diagrams measured as before, taken by

A	48.37	lbs.
C	49.90	"
Difference	1.53	"

Excess of mean pressure of *C* over that of *A*, 3.16 per cent.

As all other factors entering into the computation of the power are the same in the comparative sets of diagrams, the differences found in the mean pressures will also be the differences in per cent of their measure of the same power.

By comparing the differences in the empirical hot scales at the above mean pressures with the difference in their measures of the power, it was found, at the mean pressure of *B*, that the scale of *A* exceeded that of *B* by 4.29 per cent, while its measure of the power exceeded that of *B* by only 2.75 per cent; and, at the mean pressure of *A*, that the scale of *C* exceeded that of *A* by 0.52 per cent, while its measure of the power exceeded that of *A* by 3.16 per cent.

The weights of the moving parts of *B* and *C* were about 40 per cent greater than those of *A*, and both gave a greater measure of the power than was due to the tension of their springs by 1.54 and 2.54 per cent, respectively.

By comparing their measures of power, it was found that *C*'s measure exceeded that of *B* by 5.91 per cent, or, in other words, two instruments made by the same maker differ in their measures of the same power by nearly six per cent.

CONCLUSIONS.

The results of these tests confirm the conclusions drawn from the results of the former tests, and also show, other things being equal, that the greater the weight of the moving parts of an indicator, the greater will be its measure of the power.

THIRD SET OF TESTS.

In 1888, at the Navy Yard, New York, I was senior member of a Board appointed to make competitive tests of two indicators of the latest and most approved types, made by two eminent makers, which will be designated as *D* and *E*.

Both of the makers stated that their indicators were taken from their general stock, and that all of their indicators were tested under steam, and proved to be correct before they left their respective works.

Each indicator was furnished with four different springs of the following scales: 20, 30, 40, and 60 pounds to the inch. No cold tests were made, as it was believed to be a waste of time. The hot tests were made in the same manner as heretofore described, using a standard steam-gauge that had been compared with the mercury column to record the pressures in testing the 30, 40, and 60 pound springs, and a compound gauge that had been compared with the column for pressures above atmosphere and with the mercurial vacuum gauge for pressures below it, in testing the 20-pound springs.

All the scales of the tension of the springs made showed more or less irregularity in the lengths of their intervals, those of *D* being the greater; all of the scales were lengthened by the heat due to the pressure at which the springs were tested, as measured by the scales furnished with the springs, by the amounts given in the following table:

Scale of spring in pounds per inch....................	20	30	40	60
Test pressure in pounds per gauge....................	30	60	80	90
Increase in length of *D* scales in per cent..............	12.4	6.1	7.9	6.7
Increase in length of *E* scales in per cent..............	3.7	3.2	3.2	3.0

No mention has been heretofore made of the scales of tension of springs for pressures below that of the atmosphere, as all the pressures used in making the dynamic tests were above the atmospheric line.

It may be well to add in this connection, that scales vary as much below as they do above the atmospheric line, and present about the same irregularities in the lengths of their intervals, together with an additional one, namely:

I have observed, as a rule, in the vacuum scales made by

myself, the first five-pound interval below the atmospheric line is from 20 to 50 per cent longer than the intervals below it, and this is confirmed by the examination of several hundreds of scales made by others. Thus, there appears to be a hiatus in the resisting power of a spring, at the point where the change from compression to tension takes place, or *vice versa*, for which I can assign no satisfactory reason. The effect of this is to lower the exhaust line and increase the measure of power by the indicator.

DYNAMIC TESTS.

The dynamic tests were made by taking twenty sets of simultaneous diagrams with the two indicators from the outer end of the cylinder of the machine-shop engine in the same manner and with the same arrangement as heretofore described.

During the time the tests were being made, the revolutions were maintained nearly constant by the engine governor, but the power varied considerably according to the work being done at the time the diagrams were taken.

There were two sets of tests made: one when the indicators were fitted with 20-pound springs, and the other when they were fitted with 40-pound springs; and the power was computed in the usual manner, after the mean pressure had been found by measuring the diagrams with the scales furnished with the springs.

The results will be seen in the following table:

Scale of spring in pounds per inch	20	40
Horse-power as measured by *D*	29.09	29.76
Horse-power as measured by *E*	27.08	28.66
Difference in the measure in horse-powers	2.01	1.10
Difference in the measure in per cent	7.44	3.84

As both these indicators are considered to be first-class, and believed by their makers to be perfectly correct, how are we to decide which instrument or which spring is the more accurate measure of the power, in the absence of a dynamical standard with which to compare their measures of power?

In order to understand what the above differences mean and what they amount to, we will take the following practical example by way of illustration:

A contract has been made for a ship to be fitted with engines that must develop 10,000 horse-power at the price specified in the contract; it is also agreed that a premium of one hundred dollars ($100) will be paid to the builder for each horse-power developed by the engines upon the trial over that named in the contract, and that a like amount will be deducted from the contract price for each horse-power the engines fall below the power contracted for.

(1) If we assume that the measure of *E* is the power contracted for, and if the builder uses *D* to measure the power when fitted with the 20-pound spring, under the terms of the contract he must be paid a premium of $74,400; but if he uses *D*, fitted with the 40-pound spring, he will only be entitled to $38,400.

(2) On the other hand, if we assume that the measure of *D* is the power contracted for, then the measure of *E* falls below it by 6.91 per cent when fitted with the 20-pound spring and by 3.7 per cent when fitted with the 40-pound spring, and the purchaser is justified in withholding from the contract price $69,100 in the first instance, and $37,000 in the second.

The equities in the first instance involve the sum of $143,500 and in the second, $75,100.

The usual mode of settling in such cases is to accept the measure of the power of all indicators as being correct whose springs upon a hot or cold test, as the case may be, are found to agree with their scales within a certain limit or margin of difference. But is such a mode of settlement just to the contracting parties or creditable to the engineering profession?

CONCLUSIONS.

The conclusions to be drawn from these tests are as follows:

First. That small differences in the measure of power by indicators may involve large sums of money.

Second. That the dynamic is the crucial test of an indicator, as the indicator is essentially a dynamic instrument.

Third. That a dynamical standard is an absolute necessity in order that we may measure the power of an engine with a known instead of an assumed accuracy, and to enable

us to settle justly and equitably all questions that may arise in relation to the power developed by steam-engines.

A dynamical standard for the measure of power is imperatively demanded, not only for the reasons before given, but also in order that we may obtain more accurate and reliable data for the solution of the numerous and important problems of propulsion, traction, and motive power, to say nothing of the convenience of having a simple and sure method of testing indicators as to accuracy, instead of the radically wrong and vexatious one of testing them by the tension of their springs.

How are we to determine upon a standard indicator, and what are its essentials?

As the answers to these questions interest the whole civilized world, the subject should be submitted to the thoughtful consideration of a Board composed of representative engineers from all civilized nations, to determine upon and establish a universal standard.

It may not be amiss in this connection to briefly present my views upon this subject, which are as follows:

The ideal indicator is one without friction or weight in its moving parts, fitted with a spring of perfectly homogeneous material, unaffected by changes in temperature, and is compressed and extended equal amounts by each pound of pressure above and below the atmospheric line.

As these requirements are impossible in the physical indicator, the nearer we approach them consistent with strength, steam tightness of piston, etc., the more reliable will be the instrument.

The prerequisite for obtaining a standard is to get an engine of a known power at different speeds, using steam of varying pressures—from that needed to overcome the friction of the unloaded engine, up to the highest pressures used in the steam-engine.

If the engineer can furnish such an engine, and after some few minor points have been settled by the Board,—such as the necessary weights of moving parts, the most desirable ratio of the movement of piston to pencil, and the form and number of springs that are best adapted to meet the requirements,

—the rest could be safely left to the intelligence and skill of the makers, as they would spare no pains or expense in producing an instrument to measure a known power; or, in other words, my proposition is, that the engineer furnish a known engine-power in order to enable the maker to produce an indicator that will accurately measure the power of the engine.

To furnish the required engine presents some serious but not insuperable difficulties. Although we cannot accurately determine the power of an engine, yet we can approximate to it very closely, by using a dynamometer to measure the useful power developed (which need be but small), and by using one of our best indicators to measure the friction of the unloaded engine at the different speeds until another indicator can be made to correct its errors of measure, and then calculating with the best obtainable data the friction of the load of the engine, thus leaving but a small margin of the power in doubt.

As the momentum of the moving parts of an indicator appears to affect its measure of power, it may be found that standards for different speeds will be required; but, as that would be a great inconvenience, and involve a considerable expense in purchasing instruments, this could be avoided by using the same instrument to measure the known power at different speeds, and, from the diagrams taken, deduce the scale that measures the power at any given speed. These scales should be properly stamped with the number of the spring and the speed in revolutions per minute of the engine, and be furnished in the box with the indicator. This would involve but little expense, and avoid the necessity of purchasing and storing so many standards.

In conclusion, I may add, as to the results of the foregoing tests, they can be readily verified or disproved by any one who will take the time or trouble to do so. As to the conclusions drawn from the results of the tests, it is not expected that all will agree with mine, as each and all must draw their own from the facts before them; but, if my effort leads any here present to investigate thoroughly and exhaustively this highly important subject, the object of this paper will be attained, and I shall live in the hope of seeing established at no distant day a universal standard indicator.

DISCUSSION ON THE NECESSITY FOR A STANDARD INDICATOR.

MR. JOHN C. KAFER:—No doubt it is very desirable to have a standard indicator; but Mr. Smith does not point out how to make it, any more than he points out how to make a good rule. We have a good indicator now, that measures the power commercially, and we accept that, as we accept the yard-stick; we all buy what is called a yard of cloth at the store, but we get what is commercially known as 36 in. The same is true when we buy sugar,—we get something that we accept as 16 oz. So with the indicator, which I think is a very excellent instrument; we measure what we call a horse-power, or the pressure from which we determine the horse-power, and it is accepted by the instrument-makers as standard. If a committee, or if Mr. Smith, or any other gentleman, should point out how to make an accurate instrument, I feel sure the manufacturers would make them. We know that the instruments made by some of our best makers (notably the Tabor indicator, of which I speak from my own knowledge) are tested when hot,—tested as nearly as can be under operating conditions. I feel sure that the makers of this indicator, and probably others, would be willing to make their instruments better if they only knew how.

MR. GEO. W. DICKIE:—Just a word about the testing of indicators, and in special reference to the tests of indicators for official trials of the Government ships. They are tested very carefully by the Government experts, and a table of corrections is issued with each instrument to be used on the trial.

Now I would like to suggest, in connection with this, that, when such testing is done, instruments should be selected that are practically correct for these vessels. We have had instruments sent out to us with corrections of ten, fifteen, and eighteen per cent; and I think there was one instrument in connection with the "Monterey" trial that was twenty per cent in error, and strange to say that all the corrections for the instruments used on the trial of the "Monterey" were deductions to be made from the indicator-cards

as made by the instruments, and I can tell you we did not like that kind of correction.

In the case of the "Charleston" horse-power trials the corrections for the instruments used were all additions. That we liked much better, but when there are to be great reductions made for every instrument used, there is a hankering suspicion that it is not all right. You cannot help feeling that you are being sacrificed for the good of science or something of that kind when the corrections are in the form of reductions; but I would suggest, and I think it could be very readily carried out, that instruments used for these trials be practically correct, having no need of any tables of corrections. It would then be possible to arrive at an approximation of what is being done during the progress of a trial. But with a sheet of corrections to be applied to the card afterward, you are completely in the dark as to what is going on.

Mr. E. Platt Stratton:—In this connection, I do not think there is an instrument manufactured, from a chronometer to an indicator, for which it is not necessary to make some allowances or corrections. We have to rate chronometers; we have to rate our watches; and I suppose we shall have to rate our indicators until we find some method that gives us absolute accuracy, and I question whether it will ever be reached in our time.

Secretary McFarland:—I have personally had a great deal to do with the standardization of indicators in the trials of naval vessels, and have looked over most of the standardization tables. I want to say that, in all fairness, everybody ought to be willing to admit that the tests imposed by the Navy Department have had the effect of steadily improving the accuracy of the indicators. The first trials on which the indicators were standardized showed in some cases (not in many, I am glad to say, but in some cases) that there was a very large error at the extreme ranges of the scale. When it was found that in this way the horse-power calculated, without corrections, would be so much higher than the horse-power when corrected, it called the attention of the indicator-manufacturers to the importance of investigating the cause of these things, and now it is perfectly possible to obtain an indicator where the maximum error in any part of the scale will not be over about three per cent. The Bureau of Steam Engineering recently made a requisition for a number of indicators, in which it was specified that none would be received where the indicated error exceeded three per cent.

In regard to Mr. Dickie's point, that, "strange to say, all the corrections were deductions," I think there is a very simple and

reasonable explanation. The indicator-makers try to get the springs perfectly accurate, and they are not far out for moderate pressures, say one or two pounds at 80 to 100 lbs. pressure on an 80-lb. spring. But at higher pressures the increased temperature seems to weaken the springs so that their indication is sometimes considerably above the true pressure. Now these indicators, for the greater part of the pressures which they test, are, as I have said, not far out. If the scale was made to agree with the upper part of the range, it would register below the true pressure for the rest, and then uncorrected horse-powers would be too small. As the practice of correcting the horse-power is confined to the Navy, it could hardly be expected that the indicator-makers would make an instrument which would give too small a record for general mercantile practice. Moreover, the desire of everybody using an indicator is, as a rule, to get big results, because that means low values for coal and steam per horse-power.

In other words, the indicator cannot be made to read correctly at every part of the scale, and, recognizing this fact, it seems better to please everybody by giving it the most nearly accurate scale, but in which the error will be on the side of making the horse-power too high rather than too low.

There is nothing the matter with the corrections or the method of applying them, and if the indicators were made so that the scale was correct for the highest pressure, then all the corrections would be additions instead of deductions. In other words, if a 50-lb. spring were accidentally stamped as a 40, the table of indicator corrections would enable the true horse-power to be determined, which would be greater than that figured from the value stamped on the spring.

Mr. Geo. W. Dickie:—While the indicators are being tested they may be tapped a little to obviate any tendency of the piston to stick, but as a rule they are practically tested at rest. When applied to the engines undergoing a full-power trial the vibration is very marked. On the "Monterey" some of the instruments vibrated so as to throw off the paper cylinder. It is a very difficult matter to test an indicator under the same conditions that will obtain when the instrument is in use in an engine running at high speed, and for that reason it is exceedingly difficult to obtain on the test the conditions that can be accepted as correct for the conditions under which the instrument is used. I still think that such instruments should be selected for these trials, where large interests are involved, as will be acceptable to all parties interested

as practically correct, and have no tables of corrections to interfere with the calculations to be made after the trial.

MR. C. D. MOSHER:—Having been connected with the Crosby indicator, I had more or less to do with its perfection. It is a well-known fact that the elasticity of a spring varies according to the time it has been laid aside, or the amount of use it receives. If we are to be dependent on the spring in the indicator, absolute accuracy is out of the question; and unless some other form of spring in the shape of an air-cushion, or something that will remain absolutely constant, is obtained, I think the indicators on the market are very nearly as perfect as they can be made. I have indicated engines up to 800 or 900 revolutions a minute, and it resulted in many refinements that are not generally in use. I have been able to eliminate practically all vibration at those speeds.

PROF. JAS. E. DENTON:—Mr. Smith's paper is of great interest to me, because it gives the results of attempts to test indicators under more nearly the actual conditions of their use than are provided in the ordinary methods of calibrating these instruments. So far as I know Mr. Smith is the first to systematically compare the mean effective pressures of cards from two indicators taken simultaneously.

I have often heard it asserted that different indicators having the same scale, as calibrated by the application of steam at various pressures, determined by means of a standard gauge or mercury column, would not show the same mean effective pressure or horse-power if applied to a given engine under the same conditions.

The occasional simultaneous use of two indicators, incidentally in tests of power, has never confirmed such claims during my experience; but Mr. Smith's data and his deductions bring the question before us in such a serious aspect, that I have been impelled to institute a careful investigation over the same ground covered by his experiments. This investigation has been carried out by my associate Prof. D. S. Jacobus, and the following is an abstract of his results, which he will shortly publish in greater detail:

Four indicators were used, which are designated as Old A, New A, B, and C. They were all current, modern types, in good working order, which previous to the test had been in use as part of a private outfit of experimental apparatus prepared for use by myself and Prof. Jacobus in connection with jury work at the World's Fair, where they were freely but carefully used during the month of September. After such use they were cleaned and oiled, and

remained untouched until the experiments under notice were commenced.

The test which Mr. Smith has appropriately termed the "dynamic test" was made by attaching two instruments to branches of a tee on one end of a Buckeye engine cylinder, 7" diameter by 14" stroke, and taking simultaneous cards at about 175 revolutions per minute, and about 90 lbs. boiler-pressure.

One series of tests was made at about one-quarter cut-off, and the second series at about one-fortieth cut-off, in order to cause a loop to be formed by the expansion and back-pressure lines, with the object of exaggerating the effect of the friction of the piston upon the mean effective pressure.

After the average height of the cards was determined by preliminary experiments, the instruments were calibrated by steam-pressure, referred to a standard gauge, over the range of pressure corresponding to about one half that between the initial and back pressure of the cards, to determine what Mr. Smith has called the "hot" scale of the springs. This calibration was repeated frequently during the experiment.

The indicator Old A was used as the standard of reference throughout the tests, and it was compared with indicator B, by the dynamic tests, on every day that tests were made, so that any variation of its condition during the period of work could be considered.

The pistons of all of the indicators, except Old A, were sufficiently loose to leak steam moderately. These indicators did not give a double line for a given pressure when the pencil-point was pressed upward and downward and released slowly. Also, with the steam-pressure absolutely steady by the standard gauge, the leakage of steam past the pistons of these indicators caused a vibration, or tremor, in the pencil mechanism, perceptible to the touch, but which caused no visible motion of the pencil.

The piston of the New A indicator was sufficiently tight to make the level of the pencil perceptibly higher for a given pressure when the pencil was released after pressing upward than when it was released after pressing downward, but the difference of level was not greater than the thickness of a fairly sharp lead-pencil point. Also, there was no tremor in the pencil mechanism, the leakage of the piston being very little.

Tests 1, 2, 3, 4, and 5, Table I, and 9, 10, and 11, Table II, show the results of the work with the indicators in the condition thus far described. The general result for the one-quarter cut-off is that the average discrepancy between the mean effective pressure,

or dynamic tests of any two indicators, is from zero to about one per cent, and that the greatest discrepancy of any single pair of cards is about two and one half per cent. The latter is equivalent to about a pound per square inch, which represents a height of about 0.017 of an inch on a diagram—a distance fairly representing the error of measuring the height of a diagram by a scale with the naked eye.

The results at the short cut-off show discrepancies of mean effective pressure between any two indicators ranging from 0.2 to 0.6 lb., or, adding errors with opposite signs, about 1.1 lbs. per square inch. Stated in per cent of such small mean effective pressures, these discrepancies sound large, but they represent a distance on the diagram of only from 0.004 to about 0.016 of an inch, so that comparatively they are no larger than those for one-quarter cut-off.

It will be observed that the weight of the moving parts of these indicators varies from 18½ to 30½ grams, the B indicator having the greatest weight. It does not appear, however, that any greater error is involved in the use of this indicator by virtue of its heavier parts. This is contrary to Mr. Smith's conclusions. To check this point more thoroughly, however, the piston of indicator Old A was weighted so that its reciprocating parts aggregated 37 grams, or double their original weight, and tests were then made with it in comparison with indicator B. The results are shown in test No. 6, Table I, and test No. 12, Table II, whence it is evident that the difference between the mean effective pressures is not sensibly increased by such a variation in the weight of the moving parts.

It appears, therefore, that with indicators of any of the current first-class types, in ordinary condition, there need be no difference in the horse-power, as determined by two indicators, whose "hot" scale has been properly determined, greater than that due to accidental errors in evaluating the diagrams. This statement, however, assumes that the best of skill and care are used in operating the indicators so as to prevent irregular action of the latter. Unless the condition of the indicator piston, as regards freedom of movement in its cylinder, is maintained constant, very much larger differences than are shown by the results under notice can undoubtedly occur.

Frequent cleaning and oiling of the piston, with an intelligent appreciation on the part of the operator of the extent of the error which any inattention to this point may involve, and careful work with the planimeter and magnifying-glass in evaluating the cards, should confine the maximum difference between the horse-power,

TABLE I.

PROF. JACOBUS' COMPARISON OF INDICATORS BY TESTS AT ½ CUT-OFF.

Date of Test.	No. of Test.	Indicators Used.	Number of Indicator-cards taken.	Steam-pressure in Lbs. per Sq. Inch above Atmosphere.	Revolutions per Minute.	Weight of Moving Parts including Gravity Component of Pencil Motion, in Grams.	Hot Scale of Spring.	Mean Effective Pressure in Lbs. per Sq Inch.	Difference in Mean Effective Pressure referred to Old A. Actual in Lbs. per Sq. In.	Difference in Mean Effective Pressure referred to Old A. In Per Cent of Total M.E.P.	Difference in Mean Effective Pressure referred to Old A. Equivalent Error in Measurement of Average Height of Card in Ins.	Greatest Difference in M.E.P. between any Two Simultaneous Cards. In Lbs. per Sq. In.	Greatest Difference in M.E.P. between any Two Simultaneous Cards. In Per Cent of Total M.E.P.
Oct. 16	1	Old A	24	104.2	191.8	18.5	58.8	45.7					
		New A		104.2	191.8	24.8	61.7	45.4	− 0.3	0.7	0.004	− 1.0	2.2
" "	2	Old A	24	94.9	190.8	18.5	58.8	39.7					
		B		94.9	190.8	30.5	58.6	39.6	− 0.1	0.3	0.002	− 1.0	2.5
" "	3	Old A	24	90.7	194.8	18.5	58.8	35.9					
		C		90.7	194.9	27.0	48.8	36.0	+ 0.1	0.3	0.002	+ 0.8	2.2
Oct. 20	4	Old A	12	95.0	190.7	18.5	58.8	41.0					
		B		95.0	190.7	30.5	58.6	41.0	0.0	0.0	0.000	− 0.3	0.7
Oct. 24	5	Old A	12	94.8	196.8	18.5	58.8	40.2					
		B		94.8	196.8	30.5	58.6	40.2	0.0	0.0	0.000	+ 0.4	1.0
Oct. 20	6	Old A with weighted piston	24	94.2	192.1	37.0	58.8	41.0					
		B		94.2	192.1	30.5	58.6	40.8	− 0.2	0.5	0.003	− 0.6	1.5
Oct. 24	7	Old A with loose piston	24	94.5	192.9	18.9	59.9	40.8					
		B		94.5	192.9	30.5	58.6	40.5	− 0.3	0.7	0.005	− 0.7	1.7
" "	8	Old A with tight piston	24	94.2	192.5	19.2	58.8	39.6					
		B		94.2	192.5	30.5	58.6	39.7	+ 0.1	0.3	0.002	+ 0.7	1.8

TABLE II.

PROF. JACOBUS' COMPARISON OF INDICATORS BY TESTS AT $\frac{1}{20}$ CUT-OFF, WITH A LOOP IN THE CARD.

Date of Test.	No. of Test.	Indicators Used.	Number of Indicator-cards taken.	Steam-pressure in Lbs. per Square Inch above Atmosphere.	Revolutions per Minute.	Weight of Moving Parts, including Gravity Component of Pencil Motion, in Grams.	Hot Scale of Spring.	Mean Effective Pressure in Lbs. per Square Inch.	Difference in Mean Effective Pressure referred to Old A.		Greatest Difference in M.E.P. between any Two Simultaneous Cards.
									Actual in Lbs. per Square Inch.	Equivalent Error in Measurement of Height of Card in Inches.	
Oct. 27	9	Old A	12	94.3	180.7	18.5	58.8	7.2			
		B		94.3	180.7	30.5	58.6	6.6	− 0.6	0.010	− 0.8
" "	10	Old A	12	94.3	174.2	18.5	58.8	7.1			
		C		94.3	174.2	27.0	48.8	6.9	− 0.2	0.004	− 0.6
" "	11	Old A	12	94.8	176.0	18.5	58.8	6.9			
		New A		94.8	176.0	24.8	61.7	7.4	+ 0.5	0.006	+ 0.9
" "	12	Old A with weighted piston	12	94.8	176.7	27.0	58.8	7.1			
		B		94.8	176.7	30.5	58.6	6.4	− 0.7	0.012	− 0.9
" "	13	Old A with tight piston	12	93.8	175.5	19.2	58.8	8.0			
		B		93.8	175.5	30.5	58.6	6.6	− 1.4	0.024	− 2.0
" "	14	Old A with loose piston	12	90.7	169.8	18.9	59.9	6.7			
		B		90.7	169.8	30.5	58.6	6.5	− 0.2	0.006	− 0.5

as determined by any two indicators applied to the same engine, to the $2\frac{1}{2}$ per cent found in the present experiments from one of several sets of cards, and the average of a number of determinations then makes the difference but a fraction of this amount.

The effects of a very loose and an unusually tight piston are illustrated by tests 7, 8, 13, and 14, respectively. The loose piston was so free that the leakage of steam was very excessive, and we observe that the scale is increased about one pound by the leakage. The use of the tight piston made no difference in the "hot" scale, but the level of the pencil for the "up and down" test, during calibration, differed by one thirty-second of an inch. The tightness of the piston was not sufficient to prevent the latter from dropping freely by its own weight in the cylinder.

It will be observed that the cards taken with the loose piston, evaluated with its "hot" scale, agree by the dynamic test, as well as those with the pistons in ordinary condition (tests 1 to 5, and 9 to 11), as also do the results of the tight piston with the one-quarter cut-off. For the one-fortieth cut-off, however, in passing around the loop, the back-pressure line was lowered and the expansion-line raised in the case of the tight piston, as shown by the accompanying cards, and as a consequence the difference between the mean effective pressures of cards with this indicator and indicator B was about twice as great as with the piston in ordinary condition. (Compare test 13 with all others.) In the one-quarter cut-off cards there was no apparent effect in the location of the outlines due to the tight piston.

Mr. Smith, in his first series of dynamic tests, pages 7 and 8 of his paper, finds 5.9 per cent of difference between indicators B and C; but we are not able to judge from his data whether the standard indicator A, to which indicators B and C are referred, was in the same condition when compared with B as when compared with C. The mean effective pressure was largely different in the two series of tests, indicating that they were made on possibly different dates; and unless indicator A was compared with indicator B on the same day that the series between A and C was made, we do not know that the condition of indicator A had not changed since it was used in the A and B series.

In Mr. Smith's third set of tests, page 9, in carrying out the commercial effect of the difference between indicators D and E for a 10,000 horse-power premium contract, he uses the difference between the results of the dynamic tests and the scale of the springs given by the makers. In all important horse-power determinations by the indicator the indicator-springs would be tested,

and the scale of a spring found by such a test—that is, the "hot" scale—would be the only one used in working up the indicator-cards.

If the data on page 9 be used to determine the "hot" scales, the latter applied to the dynamic tests, on page 10, show 0.95 of 1 per cent difference between the indicators D and E for the 20 lbs. scale, and about 0.7 of 1 per cent for the 40 lbs. scale. The data on page 9, however, may not exactly apply for the range of pressure between the initial and back pressure lines of the cards upon which the dynamic tests on page 10 are based, but undoubtedly the use of the "hot" scales, as determined for the proper range of pressure in the dynamic tests, would largely reduce the differences between the two indicators applied in the 10,000 horse-power example.

Undoubtedly the indicator is not an exact instrument for the measurement of power within a certain limit, and probably in the average use of the same instrument, or equally good instruments, the measurement of power by two different experts, one representing the purchaser and the other the contractor of an engine, may, after all corrections are made by each representative, be liable to credit the engine with different horse-powers to the extent of, say, 2 per cent.

It is not probable that any improvement of the present best forms of indicator can be expected to reduce this margin of possible error in the near future, and to hope to use dynamometers with the same accuracy available from indicators is hardly a rational expectation in the light of what may be accomplished with these instruments. If we desire to avoid controversy in contracts regarding differences of power determined by use of the indicator, a step in this direction will be to assume such determinations to be liable to an error of, say, 2 per cent, and make premiums for power apply to excess or deficiency over or above the contract amount greater than 1 per cent.

Chief Engineer Smith:—I would like to ask Prof. Denton whether, in the case to which he refers, where three indicators were used, they were all used at the same moment and at the same end of the cylinder.

Prof. Denton:—They were so used.

Chief Engineer Smith:—And the diagrams were taken simultaneously?

Prof. Denton:—Yes.

Chief Engineer Smith:—Such a result surprises me, as I have never been able to get identical results from simultaneous

cards from two indicators, although I have made hundreds of such trials.

SECRETARY MCFARLAND:—In my previous remarks on this subject I neglected one point in regard to the dissatisfaction often expressed that the corrections are all deductions, so that the corrected horse-power is less than the uncorrected.

We projected a series of experiments to determine crucially whether our method of applying the corrections is the proper one, not because we had any doubt about it, but so that the matter would be settled by incontestable experiments. These experiments were partly completed by Assistant Engineer Conant, U. S. Navy, who had been devoting considerable attention to indicator-testing for several years. On our preliminary programme he was down for a paper on this subject.

The experiments were, unfortunately, not completed, owing to Mr. Conant's orders to sea, and pressure of other work not permitting their completion by others. He informed me, however, that he had gone far enough to prove conclusively that the methods of determining and applying the corrections were entirely accurate.

The plan was to take simultaneous cards with three indicators, one as nearly accurate as possible, another with a spring considerably too strong, while the third had a spring considerably too weak. A dynamometer was to be attached to the engine at the same time, to give a positive value for a portion of the horse-power.

Now, if the methods in vogue were accurate, the horse-power would be the same, after correction, by each indicator. On the other hand, if these methods were wrong, there would be great differences between the results.

I would say also, with regard to Mr. Dickie's point that the indicators of necessity are not tested under conditions identical with those of trial-trips, that the indicator-makers all claim that their instruments are as accurate at low speeds as they are at high ones.

Although I have given a great deal of attention to the matter, and have been in correspondence with men who were striving to devise an apparatus for testing the indicator at high speeds, I have not yet seen a satisfactory device for the purpose. I believe, however, that if such tests could be made the corrections required for the indicator as now constructed would be even greater than those now found.

CHIEF ENGINEER DAVID SMITH, U. S. N.:—From the drift of the discussion it appears that there is an impression that I doubt or question the usefulness of the indicator, and that I propose to

change or modify all makes of indicators without saying how it shall be done. This is a great mistake. No one prizes or appreciates the value and usefulness of the indicator more than I. Nor do I propose to change any indicator of any make, but simply to change their scales. Such a change cannot impair the usefulness of the instrument, but will enhance its value. It will, after a change of scale is made, trace the same diagram and show the internal working of the engine, just the same as it did before. I also propose to establish a reliable standard with which other indicators can be compared that will measure power with the degree of accuracy that is found in the yard-stick of the draper or pound-weight of the grocer.

Some important points that I have endeavored to make clear in the conclusions drawn from the results of the tests given in the paper submitted are, that the indicator *is essentially a dynamic instrument, is used dynamically,* and *should be tested dynamically;* that the scale of the spring furnished with the indicator cannot be relied upon to measure the diagrams taken at different speeds with any degree of accuracy, as the momentum of the moving parts of the instrument varies or changes the scale more and more as the speed increases. The instance given on page 6 illustrates this change in a marked degree.

It is there seen that at a speed of 40 revolutions per minute, the diagrams taken from the same engine, with two different indicators, when developing the same power, showed upon being measured a difference of 7.5 per cent in the power, the measure of the instrument with the stiffer spring and heavier moving parts being the less; while at 83 revolutions per minute the difference of their measures was only 0.5 per cent, that of the heavier instrument being the greater. This gives a total difference of 8 per cent in the measure of the power by the heavier instrument between the diagrams taken by it at 40 and those taken at 83 revolutions of the engine per minute, assuming that the other instrument was unaffected by the change of speed. But as the moving parts of both instruments are subject to the same laws, our second or standard instrument must have also changed its measure, so that the *apparent difference* of 8 per cent in the measure of the heavier instrument would have to be increased by the amount of the change that had taken place in the measure of the lighter one in order to obtain its *actual difference* of measure at the two speeds named.

All of these points appear to have been overlooked by those participating in the discussion, either from the lack of time on the part

of the speakers to read the paper carefully, or, more probably, from a failure on my part to clearly point them out.

It is not a question of the mechanical construction of the indicator. As Mr. Kafer well says, "We have a good indicator now;" and certainly the instruments made by some of the best makers leave little or no room for improvement, unless it may be in the greater homogeneity of the material of the spring.

Nor is it a question of the best methods of making statical tests of the indicator or how corrections should be applied, but rather one that strikes at the root of the whole present system of testing, and that is, Should any statical tests of the indicator be made at all?

I maintain that it is radically wrong in principle to test a dynamic instrument statically, and that the statical test of the indicator should be abandoned at once and forever.

What would we think of a man who would attempt to regulate or determine the accuracy of a chronometer or a watch by measuring the tension of its mainspring? Yet we are doing precisely the same thing to-day with the indicator, and it is my belief that the chances of success in either case are about the same.

What I propose is to test the indicator dynamically by actually measuring with it a power that is known. But, in order that this can be done, we must first provide the engine developing the known power. When this is done, the remainder of the work is simple. All we should have to do would be to take a sufficient number of diagrams at the speed desired, say 10, and measure their mean pressure in inches by a standard scale of equal parts, and take their mean. Then, from the well known formula for computing the horse-power, we find the mean pressure $P = \frac{\text{I.H.P.} \times 33000}{A \times 2l \times n}$; but, as all the terms on the right-hand side of the equation are known, the pressure p, in pounds per square inch, can be readily found.

If the mean pressure in inches found by measuring the diagrams be denoted by B, and the scale by C, then we have $BC = P$, and $C = \frac{P}{B} = \frac{\text{I.H.P.} \times 33000}{A \times B \times 2l \times n}$, which is the equation of the dynamic scale of the instrument for that particular speed and pressure.

To illustrate the application of this equation we will take the following practical example:

Let $A = 30$, net area of piston in square inches;
$B = 1.6$, mean pressure in inches as measured by diagram;
$P = 10$, horse-power developed by engine (known);

$L = 0.5$, length of stroke in feet;
$n = 110$, number of revolutions of engine per minute.
Then the dynamic scale

$$C = \frac{10 \times 33000}{30 \times 1.6 \times 110} = 62.5 \text{ lbs. to the inch.}$$

I apprehend no difficulty in cutting this or any other scale needed by the machines now used for that purpose.

This is the scale (with others at different speeds) that should be furnished with the instrument, and it should be clearly marked with the scale, initial steam-pressure, and the number of revolutions of the engine at which it was tested.

Such a test as is proposed can be applied to any and all makes of indicators now in use; and I believe that any old discarded hack of an indicator, so tested, would be a much more accurate and reliable instrument to measure power than the best-made instrument of any type, tested by the prevailing methods.

The proposed plan of testing contemplates the necessity of furnishing a number of dynamic scales with each spring, in order to cover the whole range of speeds likely to be needed. Although the number of such scales cannot be determined without trial, yet it is believed and confidently expected that, for differences of from 5 to 10 revolutions of the engine, above or below the trial or standardizing speed, the error of the instrument would be so small, that it could be either entirely neglected or corrected in some simple manner without sensibly affecting the accuracy of the results.* This would mean a dynamic scale for a difference of every ten or twenty revolutions to be furnished with each spring, but a trial may show that the range of accuracy may be greater than this, as the prevailing belief is that an indicator is equally accurate at all speeds.

Mr. Kafer remarked: "We have a good indicator now, one which measures the power commercially, and we accept that, as we accept the yard-scale." Now this statement is only partially true. We do accept the indicator measure of power as the commercial measure, simply because it is a Hobson's choice, as we have no other. On the other hand, we accept the yard-scale, because it has been compared either directly or indirectly with the standard yard, which is sacredly guarded by the Government, and whose accuracy has been vouched for by the sealer of weights and measures. But as to the indicator we have no such standard with which to compare its measure, and no sealers of indicators to test and vouch for their accuracy. As the case now stands, each maker has his own standard, which varies in certain cases by 5.91 per cent, as we have seen

(see page 8), and when compared with other makes of instruments their measure varies from 3.84 to 7.44 per cent (see page 10), when fitted with different springs. If such variations were tolerated in the yard-stick, we would have yards of 36, 33.87, 34.67, and 33.32 inches, respectively. And this is not all: these differences are found by comparing the measures of the instrument amongst themselves, or with other makes, without knowing that the measure of a horse-power by any of them is 33,000 foot-pounds per minute. And yet it is claimed that we have a good indicator now to measure power commercially.

Prof. Denton in the course of his remarks* says substantially, after a great many years' experience in using the indicator, that he has rarely found the springs of standard makers to greatly vary, or to change their scale even after many years, and cites the experience of Mr. Barrus as confirming his own.

Now my experience has been the opposite of this. I have never yet found, under a hot trial test, an accurate indicator-spring. I have rarely found one whose maximum error was as little as 1.5 lbs. I have also found that the great majority of springs made by the very best makers have a maximum error, ranging from three to eight pounds, according to the scale of the spring. I have also in many instances found in the course of three or four weeks that the scale of a spring had changed from 0.5 to 1.5 lbs., when the indicator was in daily use.

The experience of the Bureau of Steam Engineering, which is broader and more extensive than that of any individual, confirms the above.

The chief of that Bureau states that, under a hot test, he has never found an accurate indicator-spring; that the Bureau finds the greatest difficulty in procuring springs with small errors; that sheer necessity compels a tolerance of a variation of two and one half per cent above and below the reading of the mercury column (a total variation of five per cent), for which a correction has afterward to be made; and that the Bureau is forced to embody this margin of error in contracts for the purchase of new indicator-springs in order to obtain them.

I will here give the errors or variations taken from the official record of the tests of eight of the indicators used during the full-power trial of one of our new ships recently tried before acceptance by the Navy Department, which fairly represents the errors

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* My comments are based on the stenographer's report. I have not seen Prof. Denton's revised discussion.—D. S.

to be found in the best-made instruments. It may be here stated that the indicators were made by one of the best makers, were perfectly new, had never been used, and were considered the best that could be obtained in the market. They were carefully tested in conjunction with a mercury column which had been carefully standardized and provided with corrections for temperature. The separate lines of the scales were drawn automatically by the indicator, by means of an ingenious device, when electric contact was made at each ten-pound interval by the rise or fall of the mercury of the column, thus avoiding all possible chance of errors in observation or manipulation in making the scales.

The following are the errors found in the up and down scales:

No. of Spring.	Errors in up scale.	Errors in down scale.
	Scale of Spring, 40 lbs. = 1 in., tested to 80 lbs.	
2170	Varied from 0 to 1.5 lbs.	Varied from 1.25 to 5 lbs.
2182........	" " 0 to 1 "	" " 1.75 to 3.75 "
	Scale of Spring, 50 lbs. = 1 in., tested to 80 lbs.	
2185........	Varied from 1 to 0 lb.	Varied from 1 to 3 lbs.
2186........	" " 1 to 0.5 "	" " 0.1 to 3.5 "
	Scale of Spring, 100 lbs. = 1 in., tested to 150 lbs.	
2171........	Varied from 0 to 3.5 lbs.	Varied from 1.5 to 11 lbs.
2181........	" " − 2 to + 5 "	" " 0.5 to 10 "
2184........	" " − 1 to + 1.5 "	" " 0 to 5.5 "
2189........	" " − 2 to + 2 "	" " 3 to 12 "

The figures given above are the minimum and maximum readings of the up and the down scales, as compared with the reading of the mercury column. In order to show the irregularities of the tension of a spring at the different intervals of the scale, I will make a true copy of the record of the spring No. 2171, omitting only names, distinguishing marks, etc. (see next page).

The figures in column headed "Mean Reading" are obtained by measuring from the 0 or atmospheric line three up and three down scales with the scale (100 lbs. = 1 in.) furnished with the spring, and then taking the mean of the three measurements at each interval of the scale. The arithmetical mean of the reading of the up and down scales at any interval gives the true tension of the spring at that interval as explained on page 3.

The figures in the column headed "Error" are the differences between the corresponding readings of mercury column and measurements in the columns headed "Mean Reading." The figures in the column headed "Mean Error" are the means of the errors of the up and down scales, and show the variation between the readings

SPRING NO. 2171. SCALE, 100 LBS. = 1 IN.

Column Reading.	Mean Reading.		Error.		Mean Error.*
	Up.	Down.	Up.	Down.	
0	0	1.5	0.0	+1.5	0.75
10	10	12.0	0.0	+2.0	1.00
20	20	23.0	0.0	+3.0	1.50
30	31	34.0	+1.0	+4.0	2.50
40	41.5	45.0	+1.5	+5.0	3.25
50	51.5	55.5	+1.5	+5.5	3.50
60	62.0	66.0	+2.0	+6.0	4.00
70	72.5	76.5	+2.5	+6.5	4.50
80	82.5	87.5	+2.5	+7.0	4.75
90	93.5	100.0	+3.5	+10.0	6.75
100	103.5	109.0	+3.5	+9.0	6.25
110	113.0	121.0	+3.0	+11.0	7.00
120	123.5	129.0	+3.5	+9.0	6.25
130	132.0	138.5	+2.0	+8.5	5.25
140	141.5	147.5	+1.5	+7.5	4.50
150	150.0	154.0	0.0	+4.0	2.00

* Column not included in official record of tests.

of the mercury column and that given by measurement of the automatic scales with the scale furnished with the instrument. It is seen by examining the figures given in the last column, that the error at each interval is in excess of the column readings, which shows that the spring has been weakened by the heat by the amounts given at the respective intervals of the scale. They also show that the weakening effect of the heat follows no general law. The error begins at 0.75 lb., gradually increases, fluctuates, and reaches a maximum of 7 lbs. at the 110 interval, and then gradually decreases to 4 lbs. at the 150 interval, the last of the scale.

It is seen from the variation of the error how difficult and utterly impracticable it would be to construct a scale to conform to the irregularities in the tension of the spring unless the scale is made by the indicator itself in some such way as is described on page 3.

The errors found in spring No. 2171, as well as those of the other springs tested, are not at all exceptional, either in their character or extent, and it is my belief that they fairly represent the errors to be found in the very best-made springs. Yet we are told that the springs of standard makers are rarely found to largely vary.

The terms large and small, with their derivatives, are so vague and indefinite, that we can form little or no idea of the meaning intended to be conveyed by them until we know the relation the part bears to the whole, or have compared it with some other

standard of measure. This being the case, if we can bear in mind that mean pressure is an expensive commodity, that its value in some of our new ships ranges from one thousand to ten thousand dollars per pound, I feel assured that all will agree with me in thinking that the variation of even a pound in the tension of a spring is a large error, for which a correction should be made, when the spring is to be used in measuring power.

It was said in the discussion that we cannot take a high-pressure diagram, scale 100 = 1 in., and figure it up within two per cent. This is a very popular belief, and may be true as far as a single diagram and one individual is concerned; but if we take, say, ten diagrams, and have three persons measure them three times, and take the mean of the ninety measurements, it is believed that a much greater degree of accuracy can be obtained. Three persons making the measurements will, in all probability, eliminate any personal error, and the chances are even in measuring ten diagrams, that as many measurements will be above as below the true measurement, so that such errors will correct themselves to a great degree.

The limit of the unaided human eye in measuring with an ordinary scale is about 0.01 of an inch; using a glass of low magnifying power we can measure with a fair degree of accuracy to 0.005 of an inch, and in taking the mean of so many measurements we obtain a figure in the fourth place of decimals with a probable degree of accuracy.

For the above reasons the error in measuring the mean pressure or power of high diagrams by a scale 100 = 1 in. is very much less than that stated and generally believed.

The claims I make for the dynamic scale, made as heretofore described, are:

(1) That it will measure the power of an engine with a commercial degree of accuracy;

(2) That it will eliminate all error due to friction and the weakening effects of heat upon the spring, which will save a great deal of time and trouble in testing springs and making corrections for their errors;

(3) That it will eliminate the variable errors due to the momentum of the moving parts, which are the largest at high speeds of any of the errors to be found in the indicator, and for which no correction has heretofore been made;

(4) That it can be applied to all kinds and makes of indicators, and will make them reliable instruments to measure power without detracting from present usefulness;

(5) That it will enable us to obtain a reliable standard with which to compare other indicators in their measure of power.

If the dynamic scale was adopted it is believed that it would be much more accurate and satisfactory both to purchasers and makers of indicators, and would save the latter much time and expense in grinding and testing springs.

Under the system proposed, after an indicator has been once standardized, we could carry it about as we carry our watch, feeling confidence in its accuracy, without vexing our souls about the tension of the spring.

PROF. WM. F. DURAND (contributed after the meeting):—The subject of the testing of indicator-springs is one to which, at Cornell University, considerable attention has been paid during the past few years. In the main, two forms of apparatus have been in use, a brief description of which may be of interest.

Any apparatus necessarily consists of two portions: one for producing the pressure on the indicator-piston, and thence the movement of the pencil; and the other for determining the amount of this pressure.

For the production of pressure, the agency of steam seems the most suitable. If the spring is to be tested hot, as is usually the case, the steam acts directly on the piston. If the test is to be cold, a column of water or oil may be interposed.

The chief difference in the two methods consists in the manner of measuring the pressure produced. In one case this is done by means of a mercury column, and in the other by a beam-scale.

The variable steam-pressure is produced by means of a chamber provided with inflow and outflow valves. A small steam-gauge is also attached in order to show approximately the pressure existent at any time. With the mercury column, the steam in the chamber acts simultaneously on the piston of the attached indicator and through a proper intermediary on the mercury reservoir of the connected column.

The desired pressure being approximately produced through the proper manipulation of the reservoir valves, the corresponding altitude is observed, from which, by the application of the proper corrections, the pressure on the piston is presumably determined.

With the beam-scale, the reservoir is the same, but the steam instead of acting on the mercury reservoir acts on a plunger accurately fitted within an attached cylinder. The stem of this cylinder acts on the beam of the scale, while the cylinder itself is secured fast to the framework. With this arrangement the load on the plunger may be determined by a weighing in the usual manner.

It may be noted that the information ultimately desired is the rate of pressure, i.e., the pressure per square inch. With the mercury column this is determined simply from considerations of altitude. With the beam-scale the immediate observation relates to the total load on the plunger. It then becomes necessary to know the area of this plunger in order to determine the load per unit area. The plunger may be conveniently made of one square inch area, in which case no reduction is necessary. In any case, however, the area may be determined with an accuracy which is probably superior to that involved in the remainder of the apparatus.

In use, the cylinder containing the plunger is slightly jarred or the plunger is turned as the observation is made, thus eliminating errors due to the fit of the plunger in the cylinder.

Many refinements in detail in both construction and use are, of course, employed in the actual apparatus.

As between these two forms of apparatus, as installed in the experimental laboratory of Cornell University, the latter seems at present to give the more satisfactory results, and on the whole to be the preferable of the two.

Its advantages may be briefly summarized as follows:

It is smaller and more compact, its manipulation is easier, and the results seem to be somewhat more consistent and uniform in character.

The results of a test may be plotted with the readings of an assumed ideal spring as the abscissæ, and the corresponding errors as the ordinates. Such a representation will usually result as a line approximately straight, and inclined to the horizontal at an angle greater or less, depending on the extent of the error gradient. The equation to such a line, if straight, is of the form $y = ar$, where a is the error gradient or rate of error, r the corresponding true reading, and y the error of the spring. The actual reading of the spring will be therefore $p = (a + 1)r$. Now in an ideal spring the movement varies directly with the load, so that if u is the movement of the pencil, and the errors of the parallel motion are assumed as negligible, we may say that $r = bu$, where b is a constant depending on the dimensions and quality of the spring. It follows that the true reading of the spring is of the form $p = (a + 1)bu$. Hence if the error line is straight, i.e., if the error gradient is constant, it indicates simply that the spring is such that the load is still exactly proportional to the movement, but that it was wrongly rated. The true relation of movement to load is expressed by the ratio $(a + 1)b$, rather than by b.

With such a spring at the incorrect rating, all the readings are

wrong in the ratio of $(a + 1)$ to 1. The resultant power would be wrong in the same ratio, and hence might be corrected by a simple division with this ratio. This would be the same as assuming that the true mean effective pressure is equal to the apparent mean effective divided by this ratio, i.e., to the apparent mean effective corrected according to the determined scale of corrections.

If, therefore, the law of error is rectilinear, the application of the correction, barring effects due to inertia and lag, is very simple.

If, however, the law in question is not rectilinear, i.e., if the error gradient is irregular, the different pressures are in error by different ratios, and the resultant power will be in error by a ratio which cannot be expressed independent of the card itself. Accordingly the true mean effective pressure will not be given by correcting the apparent mean effective for the error at that particular point in the established scale of corrections.

It is due to the fact that for many springs the errors seem to be of this complex character, that so much uncertainty has arisen as to the best method of practically dealing with this question of indicator corrections. If there were no effects due to inertia and frictional lag, we could say, of course, that a new and correct card might be derived, by applying at the necessary number of points the corrections as established by the test. The amount of work here involved would usually render this procedure out of the question, to say nothing of the further uncertainties due to the omitted influences mentioned above. Some compromise is necessary, but as to just what is practically the best, authorities are by no means agreed. The case is still further complicated if there is any uncertainty as to the accuracy of the apparatus used for the test of the springs. If there is error in the apparatus, it will be combined with the true error of the springs in such a way as perhaps to totally disguise the real nature of the latter.

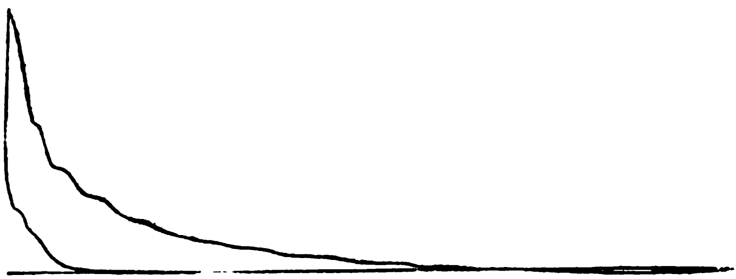
Now in cases where the errors of springs have appeared to be of variable gradient, the question may arise as to whether at least a portion of this may not be due to irregularities in the apparatus itself.

As between the two forms of test apparatus above described, it is found at Cornell University that results determined by the beam-scale show a more marked tendency to fall on a straight line, and that the results of successive tests, such as before and after use, seem to show less unaccountable variation than with the mercury column.

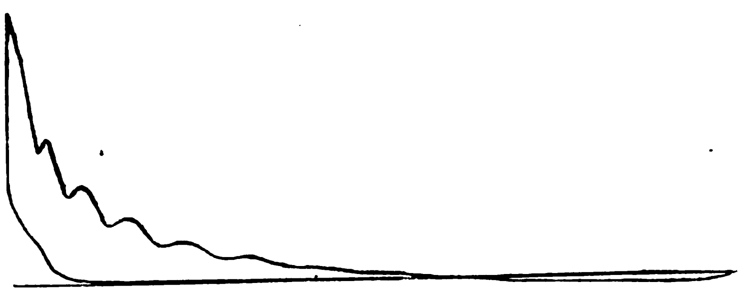
From *a priori* considerations it would seem as though the indicator-spring, with its careful manufacture and slight actual move-

ment, ought to exhibit an error of nearly constant gradient. At the same time it cannot be doubted that springs are occasionally found in which the errors are of an irregular character. It seems fair to assume that such springs should be discarded, and the makers required to furnish springs whose errors, as determined by reliable apparatus, shall substantially be of constant gradient.

It is perhaps hardly necessary to say that the test should be "hot," and as near as possible otherwise in the conditions under which the instrument will be used.



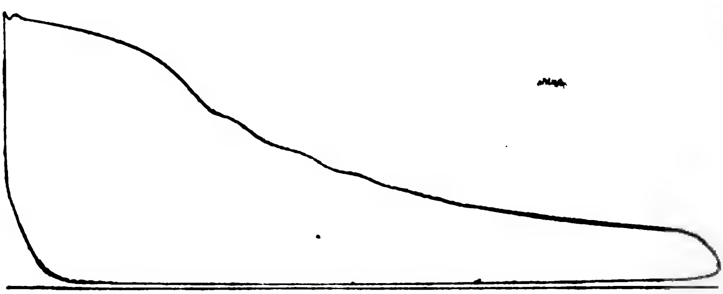
Indicator Old A with tight piston.
Hot scale 58.8 lbs. per inch.
176 revolutions per minute.
Test No. 18, Table II.



Indicator Old A with weight attached to piston.
Hot scale 58.8 lbs. per inch.
178 revolutions per minute.
Test No. 12, Table II.

Indicator Old A in ordinary condition.
Hot scale 58.8 lbs. per inch.
180 revolutions per minute.
Tests Nos. 9 to 11, Table II.

Indicator Old A with weight attached to piston.
Hot scale 58.8 lbs. per inch.
199 revolutions per minute.
Test No. 6, Table I.



Indicator Old A in ordinary condition.
Hot scale 58.8 lbs. per inch.
197 revolutions per minute.
Tests Nos. 1 to 5, Table I.

XXVIII.

THE PLANNING AND EQUIPMENT OF MODERN SHIP AND ENGINE BUILDING PLANTS.

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The business of a shipyard may, for our present purpose, be defined as the construction and repair of ships and their propelling machinery.

A ship, we may note, is simply a metal and wood structure to which, for the fulfilment of definite purposes, certain forms and dimensions must be given. The machinery likewise must be such as will insure the economic and regular fulfilment of the purposes in view.

The extent to which steel and iron are used as the principal structural material for ships and their machinery will justify the limitation of the present paper, for the most part, to the methods and tools adapted to the proper working of these materials.

We propose to examine the subject under the following heads:

(*a*) The principal structural elements which enter into a steel ship, together with the operations necessary to their preparation and consolidation into the structure of the ship.

(*b*) The machinery and methods best adapted to the carrying out of these operations, together with such items of structural equipment as enter more or less directly into building operations.

(*c*) The principal elements entering into the construction of engines and boilers, with the necessary operations as in (*a*).

(*d*) The machinery, appliances, and methods best suited to the carrying out of these operations.

(e) The best distribution, arrangement, and powering of such equipment, appliances, and machinery, looking to economy and speed in the carrying out of the work.

(a) STRUCTURAL SHIP ELEMENTS AND OPERATIONS.

The principal structural elements of a ship are: plates, beams, angles, Z-bars, channels, T's, etc., with rivets and bolts for fastenings, together with forgings and castings of steel, iron, or bronze for special parts.

We might differently divide these elements as follows:

(1) Long pieces of relatively small cross-section, as beams, angles, Z's, and channels.

(2) Flat plates, thin relative to their surface dimensions.

(3) Forgings and castings of more or less irregular form.

(4) Fastenings as above.

The operations to be effected on these materials are for the most part as follows: pickling, punching or drilling, reaming, shearing or slitting, planing and trimming in various ways, bending in whole or in part, welding or joining in various ways. To these operations on specific parts we may add the general operations of transportation and handling.

(b) MACHINERY, METHODS, AND EQUIPMENT.

The various tools and appliances for effecting these operations are, for the most part, so well known that detailed descriptions are unnecessary. We may, however, note the general characteristics and requirements relating to such machinery, these general descriptions being supplemented by lantern-slide views of tools representative of their kinds.

Pickling.—The object of pickling is the removal of the mill scale, which consists principally of magnetic oxide, and is electro-negative to the steel plate itself.

The apparatus usually employed consists of a wooden tank of such length as to take in the longest plates to be worked, and of such depth as to take the plates on edge. The bath employed is about a five-per-cent solution of sulphuric or hydrochloric acid. When removed from the pickle the plates are run between revolving wire brushes while a stream of fresh water is played on them. The immediate objects are twofold: (1) The loosening and removal of the scale. (2) The dilution and washing off of all acid remaining on the

plate after its removal from the bath. The brushes employed are five or six feet long, or slightly greater than the widest plates to be worked, and are made by setting steel wire bristles into a wooden roller or body, from which they extend some three or four inches. The brushes are usually placed vertical, to facilitate the application of the water to the plates, which, carried on rollers, are run back and forth between them.

Punching and Drilling.—The chief advantage of the punch over the drill lies in the greater speed with which it may be operated. The principal disadvantages are:

(1) A greater disturbance of the metal near the hole, and consequent weakening of the joint.

(2) Non-availability for holes in general whose length is greater than their diameter.

(3) A somewhat greater difficulty in punching the holes exactly as located.

The drilled hole, however, has a sharp edge, which must be removed by reaming, even if the hole is to remain parallel. In riveted work, moreover, the hole quite generally must be reamed to a taper. In this particular, the punched hole has the advantage, as there is less material to remove, and what is removed takes out, in large measure, the material disturbed by the passage of the punch.

The difference in speed may be partially compensated by the use of multiple drills. Their application, however, is somewhat less general than in certain other branches of engineering, due to a more irregular spacing of the holes. To make the multiple drill more nearly the equal of the punch in speed and adaptability, improvements seem to be needed along the following lines:

(1) Increase in the speed of cut. (2) Greater ease and flexibility in the location of the drills. (3) Greater regularity in the spacing of the holes.

Punches are called upon to work material, for the most part, from $\frac{1}{8}$ to 1 inch thick. The largest tools in ordinary use have gullets from 3 to 5 feet deep, and will therefore punch to the middle of a plate from 6 to 10 feet wide. There are two general types, the "lever" and the "eccentric," the latter being in more common use. The lever machine is worked by a cam actuating a lever, while the eccentric machine is worked by a pin set eccentric on the driving shaft. In the former, a

quick return is more readily obtained, thus giving a more convenient distribution of speed throughout the cycle. A nearly equivalent result may, however, be obtained in the latter by lengthening the stroke as a whole, that part of the stroke occupied in forcing the punch through the metal remaining, of course, the same.

The strains set up in punching machinery are very severe. The thrust necessary to punch 1-inch plates may reach as much as 100 tons, with proportionately larger figures for thicker plates. Such heavy periodic strains, when long repeated, ultimately rupture a cross-section of metal which, at the beginning, would have been ample. This arises from the well-known phenomenon of "fatigue" in metals. It is therefore necessary in such machinery to give to the parts actually taking the strain an excess of metal, in order that the life of the machine may be of reasonable length.

It may be suggested for such machinery that the use of a frame built up of steel plates, angles, and bars would possess certain advantages over the usual form of cast frame. It would have greater strength for the same weight or volume, or equal strength for less weight or volume. There would be no initial strains such as are common in castings, and the entire amount of metal could therefore be relied upon for the strength for which it was designed. The cost of such built-up frames would be, perhaps, somewhat greater than that of cast frames. With careful design, however, and taking into account the occasional loss of large castings, it does not seem that this difference need be great.

Reference may here be made to man-hole and limber-hole punches. These, from the nature of their work, need to be of the most heavy and powerful description. Hydraulic power, from its ready adaptation to the production of enormous pressures, is used as the operating agent.

We may also note that another method of producing such holes is by cutting, the cutter being actuated by an elliptical chuck movement. Such machines may be operated by power in the usual form (engines, shafting, etc.), require much less power than the punch, are smaller and lighter, and may be readily adjusted to cut holes of different size, and of form varying between a circle and an ellipse of the maximum eccentricity for which the tool is designed. Their chief disadvan-

tage lies in the speed of operation, which is considerably less than that of the punch.

Reaming.—Reaming tools are required to give the proper taper for flush-riveted work, or to remove the sharp edge left by the drill. The chief desiderata are speed of action and flexibility of adjustment. For the latter three courses are open: (1) To have the tool stationary and the plate movable. (2) To have the plate stationary and the tool adjustable. (3) A combination of (1) and (2).

In the first case, the plate must be adjustable in any direction horizontally. This may be attained by carrying it on a large number of cast-iron balls 2 inches or thereabouts in diameter, these being carried on a table of appropriate size. The drill or reamer spindle is then carried by an arm with at least sufficient overhang to bring it to the middle of the widest plates to be worked. Otherwise, the necessary movements of the plate may be provided by carrying it on a car running on a track, this track being carried on a second car having motion on a stationary track at right angles to the first. By this combination of motions in two directions any required adjustment may be made. In the second case, the two adjustments must be provided for the reamer. One is readily obtained by carrying the spindle on a freely swinging radial arm. A ready adjustment of the spindle along this arm provides the other, and it is believed that a gang of such reamers, each covering a convenient range, is preferable to the fixed machine and movable plate.

If it is not desired to work such tools in gang, the third arrangement, a combination of (1) and (2), may be provided. In such case, the adjustable tool is used to cover a convenient area of the plate. The latter is then shifted so as to bring a new area under the action of the tool, and so on till the entire area has been covered. For such adjustment of the plate, the cast-iron balls and table furnish every facility necessary. For the manipulation of the spindle, a lever or arm may be so arranged that, through its means, ready control of all the necessary movements, both vertical and horizontal, is obtained. With such an appliance, the time lost in withdrawing the reamer and in passing from one hole to the next is reduced to three or four seconds, so that the tool may be kept in actual cutting operation for a very large per cent of the total time.

Shearing and Slitting.—Shearing machinery is frequently combined with punching. The tendency observable in the modern evolution of machinery, however, seems to be in general away from "combinations." The chief objection to "multiple-functioned" machines lies in the difficulty, on such machines, of performing different operations with a desirable all-round efficiency. Different operations frequently require different speeds, set up different strains in the machine, and altogether suggest a more or less different form of design. Of such combinations, perhaps the least objectionable is that of the punch and plain shear.

For shearing angle-irons the standard type seems to be a double, that is, right and left hand, self-contained machine. The cutting slides are both operated from one shaft, and work downward, right and left, at angles of about 45 degrees. The general operation of punching and shearing machinery is so similar that no further mention seems necessary.

The operations of cutting or slitting may also be performed by the cold saw. The field of usefulness of this tool seems likely to increase, especially for cutting Z and channel bars either square or obliquely, or for cutting angle bars obliquely, or where it is desired to produce simply a slit, preserving the metal on both sides, as in the production of a beam knee. The tool requires considerable power, but does its work well, and leaves a clean, smooth edge.

Planing and Trimming.—Planing operations, so far as ship plates are concerned, are confined mostly to the trimming, truing, or bevelling of the edges. Planers may be arranged for working on one or two edges at the same time. In the latter case, the arm carrying the tool intended for the shorter edge or end is usually pivoted, so that it may be set at any angle between perhaps 70 and 110 degrees to the line of the other edge. The typical machine is of 20 to 30 or 35 feet in length, with an end cut of from 6 to 10 feet. The plate is usually held by a beam actuated by screws, or by jack-screws abutting against a supporting girder. Hydraulic jacks for holding the plates have recently been tried with good results. The advantages lie in greater ease and speed of manipulation. These are too evident to need special note, and the method is, in fact, the same as that which has been so successful for a similar purpose in the hydraulic keel-bending machines.

The cutter head is operated by a longitudinal screw, and is double, cutting therefore in both directions. We may here note also the use of planing operations in the formation of the vertical lap-joints as worked on the Cunard steamships *Campania*, *Lucania*, and others. The most convenient machine for this operation seems to be of the shaper type, arranged to cut on the return stroke.

Rolling and Bending.—Rolling operations on ship plates are for two purposes: (1) To straighten them; (2) to give to them a determinate curved form. Straightening rolls are usually either five or seven in number, and arranged in two tiers of two and three or three and four. The surfaces of the rolls are all in two parallel horizontal planes, and one tier, usually the upper, is carried in a movable frame so that the distance between the tiers may be varied to suit the thickness of the plates to be worked. The rolls are preferably of steel, 10 to 15 inches in diameter, and of sufficient length to accommodate the widest plates likely to be worked—say from 6 to 8 feet. The length of plate which can be operated on is, of course, indefinite.

In bending rolls the plate to be worked is operated on in the other direction. The rolls must, therefore, be of sufficient length to accommodate the longest plates to be used, even when worked through in a diagonal direction. With the growing increase in the length of plates, the longest rolls must therefore be from 30 to 40 feet long, and of sufficient diameter to withstand the excessive strains to which they are subject.

Rolls of very great diameter, however, are open to objection for two reasons: (1) Greater cost; (2) a larger portion of the plate will be left straight or unbent. In no case, moreover, can the diameter be made sufficient to prevent the roll from springing sensibly under its load. This may be compensated in two ways: (1) By giving to the roll a barrel-shaped contour, assuming that at the line of action it will spring straight. (2) By providing intermediate supports or reinforce bearings.

The first method has the advantage of simplicity, with the serious disadvantage that the amount of crown that would suit one set of circumstances will not suit another set. The use of friction-roller reinforce bearings for the support of the lower rolls has been by no means uncommon, but it is only

recently that such bearings have been applied to the support of the upper roll. It is evident that such bearings, in order to be efficient, must be carried by a girder or support of sufficient stiffness to take the load without sensible bending. When so designed, however, the use of such bearings results in an effective subdivision of the length of the roll, and the bending of such subdivided portions becomes negligible. The use of such bearings, moreover, results in a considerable increase of trunnion surface, since the load is taken not only by the main trunnions, but also by those of the various supporting rollers.

The common machine is of the well-known three-roll type, the two lower rolls being geared together and driven by the power; the upper or bending roll being adjustable up or down for varying thicknesses and degrees of bend. In such case the upper roll, whether provided or not with reinforce bearings, must admit of independent adjustment at each end, in order to provide for the production of varying bends and twists. In some cases the two driving rolls are placed one above another with adjustment for thickness of plate, the bending roll being placed at one side with independent adjustment as above. If, in the latter case, a second bending roll be added on the other side, we have the not uncommon four-roll type of machine.

In the modern type of bending machine, the upper or bending roll is controlled by mechanism, gearing or otherwise. In one machine, which has found considerable favor, the use of a friction gear is introduced, thus obviating the danger of breaking pinions or other parts through careless handling. In the same machine a double housing is used for the gears. This makes it possible to place the lower rolls somewhat nearer together than in the common type, at the same time allowing the use of larger and stronger gears. In another type of machine the same end is attained by the use of gearing on both ends, that on the farther end being actuated by a shaft passing under the framing of the machine.

A set of rolls recently installed at the Newport News Ship Building and Dry Dock Co.'s yard possesses some peculiarities which may be of interest, as indicating the latest evolution of plate rolling and bending machinery. The rolls are three in number, each 32 feet long and 16 inches in diameter. The

length of each roll is subdivided by three equally spaced roller bearings into four portions. The length of each portion between supports is thus reduced to about 6 feet, and the flexure of the roll becomes inappreciable. The upper roll and strong-back are controlled by hydraulic cylinders at each end, two for pressure and pull-back, and two for lateral movement. The lower rolls are also adjustable, each one being controlled by two hydraulic cylinders, and are both driven, one by gearing at one end and the other by gearing at the other end, through connections transmitted under the framing.

Mast rolls must be capable of rolling metal into at least a half circle of comparatively small diameter. A straight or unbent edge of any great length is also inadmissible. For these reasons the rolls must be very small, and hence the metal on which they operate has usually to be heated. If a complete circle is to be rolled, provision must be made for the hinging of one of the housings, so that either the plate may be removed over the end, or the upper roll may be withdrawn and the plate lifted. Semi-cylindrical mast sections may also be readily formed on the hydraulic keel and plate-bender, to which we next turn.

Plate rolls are evidently not available for the production of the comparatively sharp bends and turns found in plate keels or in the garboard strakes for bar keels, or in other special parts. Passing over the various types of machine which have been used for this purpose, we find the machine in favor at the present time to consist of two main elements. (1) A heavy bed-plate or base provided with hydraulic means for clamping and holding the plate, and furnished with an edge or edges over which the plate is flanged. (2) A roll or beam actuated by hydraulic power, and so guided in its motion as to produce the requisite flanging action. It is quite essential that the two ends of the flanging roll or beam have independent movements, so that one end may be worked higher or lower than the other, and thus various effects of twist or unequal bending be produced.

In earlier flanging machines the material was usually worked hot. In later machines provided with the enormous power possible through hydraulic means the material is, to a considerable extent, worked cold. This is rendered the more possible with the advance in the quality of the material used.

The plate-heating furnace and the heating operation is thus omitted, as well as any subsequent annealing operations.

In all flanging machines great strength is, of course, necessary to withstand the enormous stresses, and this calls for large masses of metal properly distributed. Both heavy plate rolls and hydraulic plate-bending machinery seem especially adapted to the built-up type of construction referred to above in connection with punches and shears, and the especial advantages there mentioned would be well brought out in such machines. This type of construction has already been successfully applied to such machinery, and its notable advantages would seem to render it worth the attention of both builders and users.

Thus far the bending machinery noticed has been for the bending of plates. We now turn to note ways and means for the bending of angles, beams, bars, etc.

Such pieces may be bent either cold or hot. Where the bending is of the amount found in frame and reverse bars, the material is worked hot; where it is less in amount, as in beams, cold bending is used. The common furnace and bending slab constitute the usual outfit for the former, and are too familiar to need more than mention. An interesting modification of the furnace, however, has recently been made with most satisfactory results. This consists in the use of oil or gas fuel instead of the usual coal. The advantages may be summed up under the heads of cleanliness, economy, quickness, uniformity. The use of this fuel, when properly burned, results in an intensely hot, smokeless flame, filling the entire furnace and raising the bar quickly and uniformly to the desired temperature.

We may next note another form of bending usually carried on at the bending slab, viz., bevelling. The usual method is by hand, and the crude nature of the results thus obtained indicate strongly the need of a thoroughly efficient and reliable bevelling machine. Such machines have already been introduced to some extent, especially in England, and have given good satisfaction. The bar is run through between conical rolls or wheels which support and hold the bar while being acted upon by the bevelling roller. The latter is controlled in position by a lever which is actuated by the operator, the position being also shown by a pointer on the scale.

A second pointer on another scale moves proportionately to the motion of the bar through the machine. Numbers on this scale refer to four-foot lengths of the bar, and opposite to them are chalked the angles to which the bar should be bevelled at the corresponding points. The operator has then simply to so manipulate the lever as to bring the bevel pointer opposite the various angles as marked on the bar scale, at the same instants that the bar pointer passes the same numbers. The bar is, of course, worked hot, and can be run through, it is claimed, at about 40 feet per minute. It then retains sufficient heat to be bent on the slab in the usual manner. The bevels as placed on the straight bar will be more or less modified by the bending, so that to obtain the best results the bevels for the straight bar should differ from those ultimately desired by a slight amount, to be determined from experience. So far, no machine has been found to take the place of the bending slab. It does not seem impossible, however, to devise some form of machine which would both bevel and bend a bar to any desired configuration.

For truing up the frames as they come from the bending slab and correcting the warp due to cooling, for giving the round up to deck beams, and for other general bending of a similar character, cold bending is used. Such operations were formerly carried on by hand, using for the purpose a heavy maul, or hand screw-press. With the extended application of hydraulic power, however, tools have been devised to perform these operations much more expeditiously and satisfactorily than was possible by hand. The general type of such machines consists of two or more fixed or bearing points, the third or bending point being the head of a light hydraulic jack, the whole being mounted on a suitable base or table. In the use of such tools, much, of course, depends on the judgment of the operator, since the bending must be carried far enough to give the necessary set to the bar, and no farther. Machines to be run by belt or separate engines are also built to attain the same end. They consist of the bearing points as above, adjustable by screw. The bending ram is given a reciprocating motion by the mechanism, and by means of the adjusting screws a variable bending stroke is obtained. Such machines are frequently made double, the ram thus operating at each end of its stroke. Other combi-

nations have also been made, such as bending and shearing, or bending and punching.

Welding and Forging.—Welding and forging operations are necessary for the production of the various forgings used in the construction of a ship, for the formation of beam knees, and for various special parts. Thus far, these operations have been carried out by the ordinary welding process under a steam hammer, or by hand. For all except the heavy ship forgings, a light single column hammer is sufficient. If the heavy ship and engine forgings are obtained elsewhere, as is quite frequently the case, a two or three ton hammer will be about the heaviest needed. Otherwise, hammers of from ten to twenty tons and upward will be required.

In view of the recent great extension in the application of electric welding, it becomes an important question as to what extent this new method may be used in ship-building work. From the great success with which it has been appliod to many classes of medium and light work, it seems reasonable to believe that this method could be applied with advantage to such operations as the following: the preparation of beam knees and stanchion ends, the joining of floor plates into one continuous piece, the joining of frames and reverse bars at the centre line of the ship, etc.

The "drop-forging" press or hammer may also be utilized to very great advantage for the production of a large number of small ship fittings, such as eye-bolts, stanchion ends, water-tight door fittings, etc.

Fastenings.—For the permanent fastening of ship material, rivets are used almost entirely, threaded bolts being used only for special purposes. Threading and screwing may therefore be properly considered in connection with engine and boiler machinery.

In some yards machines are installed for the manufacture of rivets; in others they are bought ready-made. Rivet-making machinery is so similar in general operation to that used for making bolts, nails, tacks, etc., that only passing notice is needed. Rivets are usually made hot, though the smaller sizes may be made cold.

For the *operation* of riveting, in which we are more immediately interested, we have the two methods,—by hand and by machine. The application of machine riveting to ship-build-

ing is confined, for the most part, to the riveting up of plates, bars, and angles into more or less girder-like members, such as frames and floor plates, internal keels, keelsons, stringer plates, web frames, webs and sections of cellular bottoms, etc. With machines for such purposes two arrangements are possible:

(1) The machine may be stationary, and the member to be riveted may be moved along so as to bring the successive rivets under its action.

(2) The member to be riveted may be supported stationary for the time being, and the machine may be arranged to travel along, thus coming into position to operate on the various rivets.

The latter is much the preferable arrangement, and is the more commonly found. The machine, in such case, consists of a self-contained cylinder and anvil, the former containing a ram actuated by hydraulic power, and the whole arranged so as to be slung, usually with ram working vertically, in such way as to admit the necessary motions.

It is evident that in order to bring the instrument to bear upon any rivet of a more or less irregular member, provision must be made for motion in three directions. The vertical motion is obtained by slinging the machine from some convenient form of chain screw or hydraulic hoist. For the two horizontal motions the hoist is usually carried by a form of truck or trolley running on a track, the latter being carried by a radial arm on a vertical swinging standard. With these tools the work of riveting up such members, once they are assembled, may be carried on with great regularity and despatch. These tools, to be readily portable, must be comparatively light. They cannot, therefore, be of sufficient size to work to the centre of a plate or structural member of any great width. Larger and heavier stationary machines adapted to such work will be noted in connection with boiler-shop equipment. For the riveting actually done at the ship, mechanical devices have thus far done little. The problem of how to apply the ram to one side of the ship's plating and the bearing block or anvil to the other, supporting them simultaneously when in action and shifting them readily along from one point to the next, has not yet been successfully solved.

Among the various mechanical aids which would be of dis-

tinct value to the ship-builder, few would stand higher or be more acceptable than one which would efficiently replace the ship-riveter's gang. The solution must come in one of two ways: (1) The devising of a tool which will efficiently secure *rivets* in a ship's hull; (2) The substitution for *rivets* of some other form of fastening more amenable to mechanical treatment, and which shall be equal or superior to it in efficiency as a fastening. An attempt has been made to utilize the force of magnetic attraction to hold together a machine-riveter and its anvil on opposite sides of the ship's plating. The holding power in such case is, of course, much less than would be required to stand the steady thrust of hydraulic riveting. The apparatus has, however, proved too heavy and difficult of manipulation for satisfactory use. A pressure of about 100 pounds per square inch cross-section of magnet cores is about the maximum that can profitably be attained by such means. It is therefore not difficult to see that, in order to obtain holding power sufficient to withstand power riveting by hammer, to say nothing of hydraulic riveting, the apparatus involved must be very heavy.

Chipping and Calking.—Chipping and calking operations have, until quite recently, been performed by hand. We have now available for such purpose, more especially the latter, magnetic and pneumatic tools, by means of which the work may be done quicker, easier, and more uniformly than by hand. A tool of this character is simply a small, light, power-hammer, the reciprocating movement being obtained in one case by magnetic means and in the other by compressed air. The latter form of tool seems at present to possess some advantages in the way of adaptation to varying classes of work, and is, in fact, the only one in common use. The principal uses of compressed air on board a ship under construction or repair are to furnish motive power to pneumatic calkers, and blast for rivet forges. The latter could readily be furnished by small blowers run by electro-motors, and if an electro-magnetic calker could be made the equal of the pneumatic tool, the use of compressed air as a motive power could be dispensed with, and with it the fitting of a special line of pipe for its conveyance. This subject will be noted again in connection with the subject of "Distribution of Power."

Transportation and Handling.—Among the various problems involved in the efficient production of a steel ship and its machinery, none is of greater importance or more difficult of entirely satisfactory solution than that of transportation and manipulation. From the similarity of the operations involved, this subject may be considered in relation to both hull and machinery.

Up to within a few years, the appliances used for these operations were of the crudest. Manual transportation by a gang of men; hand trucks hauled by workmen, or trucks hauled by oxen or horses; and for lifting, rope derricks operated by workmen or by oxen and horses,—were all in common use, and are still by no means unknown. With the general specialization of the functions of men and machines, however, and with the general tendency to substitute, where possible, mechanical for organic power, such means are no longer to be considered satisfactory. The general object to be obtained is evidently, so far as possible, the complete control and transportation of the piece under operation by mechanical rather than by manual means.

With the present modes of hull construction, the actual weights to be handled are for the most part comparatively small. Their sizes and forms, however, are frequently such as to render them very unwieldy, and the practical solution of the problem of transportation depends upon these elements more than upon that of weight. With engines and boilers, great weight as well as unwieldy forms have to be handled, and in the appliances used, great strength as well as capacity for handling such forms must be provided.

We will first note the two sub-heads:

(1) *Manipulation*, or the handling of a piece while undergoing operation at some machine.

(2) *Transportation*, or the carrying of a piece from one point to another.

Of the latter we readily note the following varieties:

(*a*) Transportation of raw material from railway cars to stock piles, from one part of the yard to another, or from stock piles to the shops.

(*b*) Transportation of pieces within the shops.

(*c*) Transportation of a part from one shop to another, or of a completed element from the shop to the ship.

(*d*) Placing the part or element in position on or in the ship.

For manipulation, the appliances are various—according to the nature of the part in question and the amount and kind of handling necessary. Some form of jib, pillar, or wall crane, with or without travelling trolley, and with or without hydraulic hoist for the arm and pillar as a whole, is most commonly used. Such tools are applicable to the handling of pieces of light or moderate weight, such as plates, deck-beams, angles, and the multitudinous small pieces which are handled in the boiler and machine shops. The motive power for such cranes is either hand or hydraulic—preferably the latter. Electric power might also be applied, though its advantages are more especially marked when applied to cranes of the "travelling" type. For indoor conveying, or conveying and manipulating, the appropriate appliance depends on the weight and size of the pieces to be handled. For light pieces, small platform or box cars running on a narrow-gauge railroad, and pushed by hand, are not uncommonly used. A great improvement for many purposes consists in the use of a form of light single-rail trolley, serving as support for some approved form of hydraulic or chain hoist. The trolley with its load may be readily moved along the track by hand, and by means of a series of switches any point in the desired floor area may be covered. So far as the writer is aware, the addition of a light electric motor to such a form of trolley has not yet been used. There would seem, however, to be useful possibilities in such a combination. The overhead trolley, compared with the surface road, would possess advantages in lightness of running gear and in less obstruction to the floor area. Where power is distributed largely by belts, there might be some difficulty in carrying the trolley wherever desired. With the increasing use of independent engines and electric motors for driving ship-yard tools, however, this objection disappears. The addition of the small motor to the trolley would result in increased capacity and in greater ease and speed of transportation and handling. Such a light trolley-conveyer is, in fact, simply a small self-propelled travelling crane, capable of running on curved tracks and rounding corners, and well suited to a large variety of conveying purposes.

For conveying, or conveying and manipulating larger pieces, whether in the plating, machine, or boiler shops, foundry or forge, the usual type of appliance is the well-known bridge travelling crane. The girder or bridge is of sufficient length to span the entire width of shop, and is propelled by appropriate means from one end to the other. A heavy trolley, through appropriate connections with the power, is propelled along the bridge, and therefore crosswise of the shop. The vertical motion is provided by means of the usual form of chain hoist. Usually, intermediate gearing is provided for two or three ranges of speed, and sometimes two hoists are provided, one for pieces of comparatively light or medium weight, the other for the heaviest pieces which the crane is capable of handling.

For transmitting the power to these cranes, three methods may be noted: (1) by square shafts; (2) by rope bands; (3) by trolley wire to electric motors. The latter has only recently been introduced, but is rapidly displacing the other methods. The advantage lies in better control, and greater speed and handiness of manipulation.

A description of the approved type of electric travelling crane in some greater detail may not be without interest. The following data relate to the construction and performance of a crane of this type recently installed at the Watervliet Arsenal, West Troy, N. Y. They are taken from a paper read before the American Society of Mechanical Engineers at their fall meeting, November, 1892, by Mr. Anthony Victorin.

The crane has a span of 60 ft. There are two hoists, the main one having a capacity of 120 tons and lift of 40 ft., the smaller having a capacity of 10 tons and lift of 56 ft. The total weight of the whole crane is about 150 tons. The bridge or main girder rests on eight double-flanged wheels of 36 in. diameter, the trolley on 16 wheels of 24 in. diameter. All wheels are arranged in pairs in compensating beams, to avoid inconvenient results from lack of uniformity in the level of the track rails. All wheels have anti-friction steel roller bearings. The motor is at one end of the bridge, and receives the current through a bare copper wire strung on insulated rollers along the crane-ways. The motor is in permanent gear with a clutch-shaft which is provided with four clutch-gears. Two square driving-shafts, (*a*) and (*b*), are located on

the bridge; (*a*) operates, through the clutches, the bridge and trolley travels, and the auxiliary hoist; (*b*) operates similarly the main hoist only. Following are the varying speeds of operation:

Bridge travel........................	40 and 80 ft.	per	minute.
Trolley travel........................	50 " 100 "	"	"
Main hoist........................	2, 4, 8, 16 "	"	"
Auxiliary hoist	20 and 40 "	"	"

Automatic brakes are provided to sustain the load in any position. The trolley is provided with two grooved chain drums, each being capable of winding 250 ft. of one and one quarter inch main hoisting chain. These drums revolve loose on trolley axle-shafts 7 in. in diameter, with bronze bushed bearings of 24 in. length at each end. The lower sheave-block has 6 bronze bushed sheaves of 30 in. diameter, and the upper block 5 similar sheaves of 33 in. diameter. The operating cage contains all manipulating levers, switches, and rheostats. All motions of the crane are independent, and can therefore be in operation simultaneously. All gears except those on the main chain drums are cut, and throughout special care was taken to reduce the losses by friction to a minimum.

The crane is operated by a single electric motor furnished with current at 500 volts by a 65-H.P. dynamo. The performance tests included measurements in detail of the power required to operate the various portions of the mechanism. Without noting these in detail, it appeared that in spite of the careful construction a large portion of the driving power is absorbed by friction, and that the efficiency as a whole will range from about 25% for the slowest speeds with the greatest number of gears in operation, to about 50% for the highest speeds and fewest number of gears in operation. It was also found that the power required to bring the mechanism to speed from a state of rest was very considerable, varying under different circumstances from 30% to 150% of the power required to continue the operation once the speed attained.

As showing the latest development of such cranes, the following description of a 50-ton crane recently installed at the Newport News Ship-building and Dry Dock Co.'s yard may be of interest:

The span is 49 ft. 9 in., and the total run 298 ft.

The shipping weight was about 55 tons.

The maximum bridge speed with the crane operated light will be from 225 to 250 ft. per minute, and when handling full load 125 to 150 ft. per minute.

The transverse or trolley traverse will be 100 ft. per minute light, and 40 to 50 ft. per minute with full load.

The hoisting speeds will be: for the empty block, about 30 ft. per minute; with 15 tons, about 12 ft. per minute; and with 50 tons, about 4 ft. per minute.

Each movement is operated by an independent electric motor—one for bridge traverse, one for trolley traverse, and one for hoisting. These motors are capable of exerting about 20 to 25 H.P. for the hoist, 20 H.P. for the bridge, and 6 H.P. for the trolley traverse. These motors are all series-wound, and the speeds are controlled by rheostats. The hoisting motor, however, is back geared by a single pair of magnetic clutches, thrown into operation when hoisting 15 tons or over, thus giving a higher gearing ratio than that used for lighter loads. This gives a higher average efficiency to the motor than if used for all loads without change of gear ratio, and also a greater range of speed with a given waste in the rheostats.

The crane is carried on eight truck-wheels, four at either end. These wheels are journalled in equalizers, so that the load is always equally distributed over the four wheels at either end.

The three-motor type of crane possesses advantages over the single-motor type in the suppression of all reversing clutches, and in the great range of speed obtainable by varying the speed of the motors themselves. Any of the movements of a properly constructed three-motor crane may be operated at any speed desired, between zero and the maximum speed for any given load. The change of speed involves no special manipulation on the part of the operator, as it is dependent simply on the distance which the reversing lever controlling the given motor is moved from a central position. The direction of movement depends on whether the lever is swung to one side or the other of the mid-position.

In order to obtain accurate control over the load in lowering, and eliminate any danger of racing in lowering, or of dropping the load on account of failure of current, or from

carelessness of the operator, it is found advisable to use two brakes in the hoisting train—one a mechanical brake which sustains the load automatically, being applied by the action of the load itself, and withdrawn in lowering by the action of the motor. The lowering motion thus ceases instantly when the pull of the motor releasing the brake ceases, and proceeds only at equal speed with the movement of the motor. The second brake is applied by powerful springs, and is withdrawn when the motor is in motion by the action of the current passing through solenoids in series with the motor itself. If this brake were not used, the momentum of the armature would be sufficient to continue the movement of the load for some little time after the current was shut off. By the use of these two brakes absolute control of the load while in motion is assured, as well as instantaneous stopping of the same when the reversing lever is thrown to its mid-position, and the current cut off.

In this connection the following results of the test of one of a pair of electric cranes recently installed in the foundry at the United States Navy Yard, Brooklyn, may be noted:

Weight lifted	15 tons.
Speed	8 ft. per minute.
Work done at the hoist	7.8 horse-power.
Electrical work developed in the dynamo	24.1 " "
Combined efficiency of motor and crane	80%.

For the conveyance of material back and forth between different floors of the same shop, as in the case of a machine-shop with elevated side galleries, some approved form of freight-elevator of the usual type will be required.

We may next turn our attention to outside or yard conveyance. A large variety of service is here required. Stock is to be unloaded from railway cars and sorted in racks or piles; the same stock is to be transported from the racks to the various shops, or from one shop to another in the course of its preparation; the various parts and members of the hull after preparation in the shops have to be transported to the building-slip and there placed in position on the ship; after launching, the engines and boilers and the various auxiliary machines, as well as masts, armor of war-ships, and various other portions of the equipment, have to be transported from the shops to the dock or fitting-out basin, and placed in posi-

tion on the ship. Naturally these various services do not all call for the same type of apparatus.

One of the most generally useful, however, is some form of self-propelled travelling crane. One type, of which several are in successful use, consists of a base carried by appropriate trucks, and self-propelled on a broad-gauge railroad. A built-up column supports a double cantilever, which with the column has a motion of rotation about a vertical axis, the whole being supported by trucks resting on the base. The motion along the track combined with the motion of rotation and with the vertical motion, obtained by any approved form of hoist, provides the three motions necessary to reach any point in space within its range.

The dimensions and capacities of these cranes as installed at Newport News, Union Iron Works, and elsewhere, are about as follows: Total length of cantilever, 124 ft., or overhang on each side, 62 ft. The gauge of the railway is 18 ft. 10 in. The lifting capacity at extreme end of arm is 3 tons, with proportionate increase for points nearer the centre up to about 10 tons as a maximum. The maximum speeds are as follows:

Crane on track	200 ft.	per	minute.
Crane revolving	1¼ revolutions	"	"
Trolley on tramway	500 ft.	"	"
Hoisting	50 to 150 "	"	"

A scale for weighing, with capacity of 15 tons, is also provided on the tramway. The lighter capacity is ample for most of the work required of these cranes, and when so working it is evident that they command, in any one position, all points within a radius of 62 ft. All unloading and distribution of ship material, as well as its transportation to the shops or from the shops to the building-slips, is readily performed by such cranes.

Another method for the distribution of material as used at the Union Iron Works, San Francisco, Cal., may be here noted. The racks for the stacking of material extend on each side of the railway track by means of which the material enters the yard. Spanning the railway track and both rows of racks is a bridge travelling crane, rope-driven, of 6 tons capacity. By this means, all classes of ship material are quickly unloaded from the railway cars, and sorted in place.

The same crane serves also for loading the same material on smaller cars, by means of which, over a system of distributing tracks, it is transported to the various shops as required.

Another form of outside conveyance is by means of trucks or platform cars running on railways of narrow or ordinary gauge. A light dummy locomotive furnishes the necessary power, and is capable, of course, of handling several such cars. The function of these cars is transporting wholly, and they can be used, therefore, only in connection with cranes, either locomotive or stationary. Since such cranes should always be provided in the various shops, at the building-slips, and docks, it is evident that cars are an appropriate means of transportation between such points. Heavy cars similarly handled are of especial value in the transportation of engines and boilers from the shops to the docks.

We may next note means for handling building material at the slips. Up to within a few years, the principal means employed consisted of a number of stationary derricks or hoists, placed at convenient points, each one capable of serving a certain part of the ship. Recently travelling cranes of one form or another have been largely introduced, one or two such cranes being capable of serving any and all points of one or more ships under construction. Typical examples of these cranes are found at Newport News, and at the Union Iron Works.

At the former yard a narrow elevated permanent trestlework or staging runs back from the water-front, a building-slip being arranged close on either side. This staging carries a track, on which runs a double-cantilever crane, similar in type to that used as a yard crane, but without the motion of revolution. The overhang is sufficient on both sides to enable material to be readily placed at any point on either ship. There are two such trestles and cranes at this yard, the larger having the following principal dimensions: Length of trestle, 740 ft., being sufficient for a ship 650 ft. long, or with slight addition for one of 700 ft. Length of transverse runway, 178 ft., which gives sufficient breadth to span two ships 70 ft. beam. The crane travelling upon this trestle will be 95 ft. between the arm and the ground at the upper end of the ways. The gauge of the longitudinal railway is about 20 ft. The capacity of the crane is 9000 lbs. at the extreme

end, increasing to 25,000 lbs. at a point 53 ft. out from the centre. This crane will be operated entirely by electric motors. The speed of operation of these cranes is about the same as that of the yard cranes previously noted, viz.:

Longitudinal....	200 ft. per minute.
Transverse................................	500 " " "
Hoist..............................	50 to 150 " " "

Let us assume the average length of longitudinal run to be 250 ft. for a ship 400 ft. long, and the average length of hoist to be 50 ft., and of lower 40 ft. The transverse movement can usually be effected simultaneously with the longitudinal, and therefore requires no extra time. Assuming, then, mean values for the speeds, it follows that the average time required in transit between the points of receipt and delivery will be about 2.8 minutes. The return will be somewhat quicker, so that the round trip will require about five minutes as an average. This is, of course, the time in transit, and does not include the time spent in hooking, placing, securing, and unhooking. It may be readily seen, however, that for handling the structural material of a pair of ships the capacities of such cranes are ample, both as regards speed and lifting-power.

The specialization of the hoisting and distributing function to this one machine controlled and operated by one man seems to be a step in the right direction; and the only objection to such centralization, viz., that hoisting cannot be going on simultaneously at different points, disappears when we consider the fact that whether hoisting is done simultaneously or seriatim, the machine has abundant capacity to keep the various gangs of men fully occupied.

At the Union Iron Works, the staging consists of a skeleton iron and steel structure extending on both sides and over a single building-slip. The structural members consist of upright and roof trusses, these being so braced and tied as to make a very strong and rigid structure. The ordinary ship staging is all carried from the side girders, while the roof trusses carry the rails for a pair of bridge travelling cranes which command every part of the ship under construction beneath. The two cranes on each slip are complete in themselves, and independent of each other in their operations. Each crane travels longitudinally the whole length of the slip and commands one side of the ship, one of them, however,

being 3 ft. longer than the other, to command the centre or keel line. These cranes are of 6 tons capacity, and have a traversing speed of 150 ft. per minute.

Another form of appliance, built by the same firm as those above mentioned, is in use at the works of the Cleveland Ship-building Co. This also is intended for one ship only, and consists of a pair of bridge travelling cranes supported at each end on a trestle-work built up on each side of the ship, each crane spanning the entire width. Still another form from the same builders is in use at the yards of F. W. Wheeler & Co., West Bay City, Mich. This consists of a combination of bridge with cantilever extension. The latter is 55 feet long, which is sufficient for the ordinary classes of Lake shipping. The tramway is 100 feet long between supports, one of which is a trestle alongside of the ship, while the other is the side of a long shop in which the ship material is prepared. The crane thus covers all points both of the ship and of this intervening space. A surface railway runs down this intermediate space, which thus becomes suitable for the storage of stock. In this way one crane is made available for all the various outdoor transporting and distributing functions which we have thus far noticed. This comprehensive system would not, however, seem to be as well suited to the case in which several ships are to be furnished with material from one set of shops.

We have next to note the appliances necessary for placing heavy weights, such as engines, boilers, armor-plates, etc., on board the ship after launching.

Two appliances are in use—stationary shears and floating derricks. The former consists of the well-known three legs in tripod form, the two front legs being hinged near the dock front, while the third has a motion toward and from it. This movement gives a traverse to the shear head of from 10 to 20 feet within the dock edge to 30 or 40 feet beyond it, the object being to reach somewhat past the midship line of any ship likely to be handled. The legs of these shears are usually built up of steel plates, trussed and stayed for stiffness and strength. The movement of the rear or longest leg is usually given by means of a large screw working in a nut to which the leg is secured. With the growth of guns and armor, and more especially of engines and boilers, has come

the necessity of increased capacity in such appliances, and shears capable of handling loads of from 100 to 125 tons are no longer unusual. This appliance is in such general use that no further mention seems necessary.

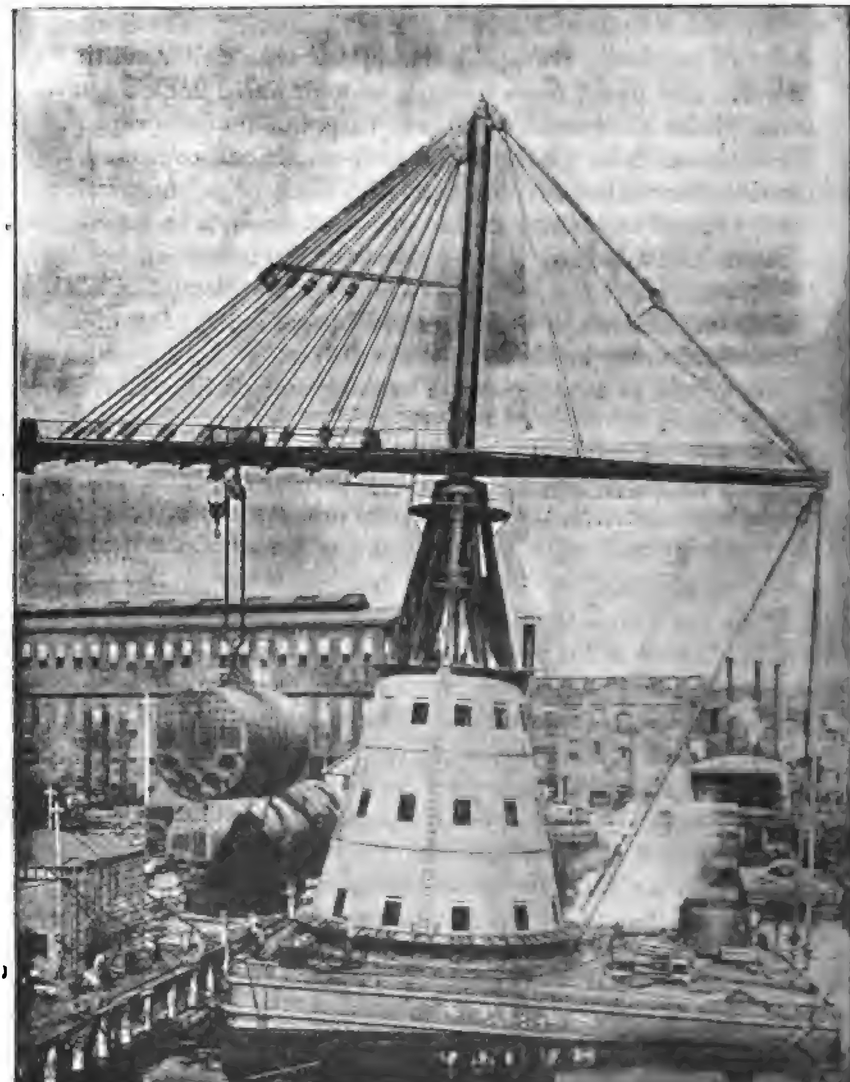
The floating derrick has the advantage over the stationary shear of providing transportation by water as well as lifting-power. The usual form consists of a single or double cantilever girder supported by a float or pontoon of appropriate dimensions. The girder must have sufficient overhang to provide for taking articles from the dock edge and placing them at least amidships in the broadest ships to be handled. A derrick of this type with a capacity of 120 tons has recently been installed at the yards of Wm. Cramp & Sons, Philadelphia, and is shown in the annexed illustration. A few of the chief details may be noted.

The hull is rectangular in section, and of the following dimensions:

Length	73 feet.	
Breadth	69 "	
Depth	13 "	4 inches.

It is subdivided into 20 water-tight compartments. The tower is mounted on the middle line, near one side in order to give the boom the maximum overhang. There are five compartments at the rear of the pontoon, which may be independently filled with water, thus serving as counterballast for extra-heavy lifting operations. The remaining fifteen compartments are heavily ballasted with cement, which, with the water mentioned above, serve to provide the necessary stability.

The tower is built of 12 columns, each made of two 12-inch channel-bars placed back to back, resting on and bolted to the base piece, which is 40 feet in diameter. These columns at the top are bolted to the crown casting through which the mast, 40 inches in diameter, passes to the step casting, 15 feet below and 11 feet in diameter. The step is provided with steel balls 4 inches in diameter for taking the vertical thrust of the mast. The step casting is hung from the crown casting by 12 one and a half inch bolts, thus transmitting the vertical load to the columns, and thence to the float. The boom has a height of 65 feet above the deck, which will provide for an estimated clear hoist of 40 feet. The overhang is about 35 feet.



130-TON DERRICK AT CRAMPS'.

The mast rises to a total height of about 110 feet above the deck, and is surmounted by a cap casting, to which are attached a series of ties supporting the front boom, and a heavy trussed strut to assist in the support of the back boom. The latter is also supported by the back-stays which lead from its outer end downward to the back-stay carriage at the foot of the tower. The pressure at the back-stay carriage is taken by steel rollers. These, in connection with the step ball-bearing, provide for the horizontal swinging of the boom. The boom itself consists of two box girders, the upper surfaces of which are provided with sliding ways of planed brass, on which run, on lignum-vitæ slides, the sheave carriage. This measures seven and one half feet long by two feet wide, and supports two lifting tackles—one the main hoist with a twenty-fold purchase, the other a single fall for light lifting.

The light hoist and manipulating machinery are driven by a pair of engines 14 inches diameter of cylinder by 12-inch stroke, connecting through wedge friction-gear. The main hoisting drum, which is 5 feet in diameter by 8 feet long, is driven independently by a pair of the same-sized engines, connected through gearing. The slowest speed of hoist is 4 feet per minute, while lowering can be carried on at any desired speed. Two men are sufficient for the manipulation of the derrick, and by its means a 70-ton boiler has been lifted from the dock, towed a distance of 150 feet, and lowered into the cruiser *New York* in 25 minutes.

Another form of lifting and distributing appliance, differing somewhat from those previously noticed, has recently been installed at the Brooklyn Navy Yard for dry-dock service. The docks are each surrounded by a broad-gauge railway, on which travels a self-propelled jib crane. These cranes have effective radii variable between 56 and 70 feet, and revolve horizontally on the base which supports the crane proper. This base, in turn, is supported on a compound sixteen-wheel truck. The capacity of these cranes is 40 tons. Similar cranes of smaller capacity are installed at the Union Iron Works and elsewhere.

We have thus passed rapidly in review the chief tools and appliances used for the working and manipulation of the metal parts of a ship. As to wood-working machinery, the

usual line of sawing, planing, shaping, and forming machinery will be required, but the substantial identity between the machinery suitable for shipyard work and for wood-working in general seems to render special notice unnecessary. The general tendency, however, as manifested in the equipment at Newport News, seems to be toward the provision of special machinery and cutters for the production of special forms which would otherwise have to be worked out by hand.

DRY-DOCKS.

The materials of which dry-docks are constructed are two—stone and wood. In the United States the latter is in very general use, all of the largest docks being of such material. The selection of wood rather than stone for dry-docks, at least for the climate of the Northern and Middle States, seems justified by the following general comparison :

Time required for Construction.—The largest timber docks constructed, having lengths of from five to six hundred feet, have been completed in from two to two and a half years. Adjacent granite docks, constructed in similar strata of soil, and under similar climatic conditions, required from nine to ten years for their construction. The granite docks, however, were constructed many years previous to the timber docks, and in the mean time the appliances for excavating and handling material have been so improved, that at the present time the difference would be by no means so extreme. On the other hand, the timber docks are about 150 feet longer than those of granite, so that this may serve in considerable measure as an offset to the improvements in appliances and methods of work. It is quite evident, however, from the lightness and nature of the material, that it may be worked in much larger pieces, and that the entire operations of handling, fitting, and securing may be effected with very considerably greater speed.

First Cost.—The timber dry dock at the U. S. Navy Yard, New York, completed in 1889, is of the following principal dimensions:

Length on top	500 feet.	
Width on "	130 "	4 inches.
Width on bottom	50 "	
Width at entrance	85 "	
Depth of sill below high water	25 "	6 inches.

This dock was constructed at a total cost to the Government of $565,892.63.

The granite dock adjacent, one of those referred to above, and having a length of 359 feet, with other corresponding dimensions, cost, at the time of its construction, nearly four times this sum.

Any direct comparison, however, based on these figures would be seriously at fault without making due allowance for the difference in cost of labor and material, in the means available for such work, and in the general conditions under which the two docks were constructed.

Cost of Operation.—With equal facilities for pumping, handling the caisson, warps, shores, etc., there should be no especial difference in the expense of operating timber and stone docks. The average cost of docking vessels of about 3000 tons has been estimated by Messrs. Cramp & Sons at about $29.00 per thousand tons, based on the results of a year's working.

Durability and Cost of Maintenance.—With a foundation properly prepared, and in a climate not subject to serious frosts, the life of a stone dock would evidently be of indefinite extent. Unfortunately the latter condition is not fulfilled in most parts of the United States where dry-docks are employed.

As a consequence, the joints are liable to become broken, thus giving rise to serious leaks, and requiring extensive and costly repairs. Furthermore, the very much greater weight of the stone as compared with the timber dock renders the preparation of a thoroughly permanent foundation much more difficult. In other words, with a given foundation a stone dock is more likely to settle than a timber dock, thus again increasing the likelihood of repairs for the former. The stone dock at the U. S. Navy Yard, New York, was completed in 1851. After about 33 years' service it had deteriorated to such an extent that repairs aggregating over $100,000 were necessary. This is perhaps an extreme case, but it shows the deterioration which resulted under the special influences to which this dock was subject.

In the case of timber docks, granting again a permanent foundation, the structure, being kept constantly wet, is practically of indefinite duration. Experience has shown that the deterioration is restricted almost entirely to the face timbers below high-water mark, and to the general structure above

that point. The life of such portions of the first specimens of timber docks have been found to be from 20 to 30 years. In later docks of this type, the timbers have been treated with creosote or by other preservative process, by which means it is believed that the life will be materially lengthened.

General Adaptation.—The greater slope naturally given to the sides and heads of timber docks, and the dimensions of the altars used, provide safe and easy means of passage for workmen to and from the floor of the dock direct at any point. The same feature also gives more light on the bottom of the ship. The air in stone docks in winter is necessarily damp and chilling. This is in large measure avoided by the use of the timber floors and altars. Again, the rise of the altars being but 8 inches, and the slope of the sides being so gentle, it becomes possible to use one set of side shores for nearly all sizes of vessels.

Construction of Timber Docks.—The principal structural features of timber docks as constructed on the Simpson system may next be noted.

The site being chosen, an excavation of the proper form and dimensions is made. In the usual case, the substrata are of sand or mud, requiring special provision for the support of the weight of the vessel to be docked. This is provided by driving in piles spaced closely along the longitudinal centre line of the dock, and more openly on the sides. Piling is also usually driven for the support of the altars as well as the floors. The floor piling being driven, the tops are levelled off and longitudinal timbers are secured to them. Concrete is then filled in, making a flush surface. Transverse beams are then laid and secured to the longitudinals. On these beams the floor is laid with open seams. The cross beams extend out beyond the side string-pieces, and on them rest timbers which support the altars, such timbers being further supported by piling when it is driven.

One of the principal problems connected with the construction of dry-docks is that relating to proper provision for supporting or relieving the upward hydrostatic pressure to which the bottom of the dock may be subject. With timber docks special valves are placed at various points in the floor in order to relieve it of this pressure. Such a valve consists of a tube set into the earth and extending down into the water.

bearing strata. The lower end of the tube is perforated for the ready ingress of water. The top rises slightly above the floor of the dock and has a valve arranged to open upward under a slight head, but to close automatically under the absence of such pressure, and thus prevent the flow of water from the dock when flooded down into the underlying strata.

If, instead of sand or mud, a hard bottom is available, the piling is omitted and the floor is fitted as follows: The excavation being made, a bed of concrete is laid, anchors made of bar-iron with flanged lateral projections having been previously placed in position. Longitudinal timbers are then laid on the concrete and secured to the anchors, after which concrete is filled in flush with the top of these timbers. Cross floor-beams are then laid, and the construction carried on as above.

The caisson, pumping-well, etc., present no especial peculiarities and need no further mention.

CAISSON AND HYDRAULIC LIFTING DOCKS.

The nature and operation of the former type are too well known to need special mention. The chief advantages of such docks are small relative cost and mobility.

As an example of the hydraulic lifting dock, a brief description may be given of a dock of this type as installed at the Union Iron Works.

The floor of the dock consists of a platform 62 feet wide by 435 feet long, built of cross and longitudinal steel girders, with keel and sliding bilge-blocks. The lifting-power is obtained from a set of hydraulic pumps working through a weighted regulator, the load on which is varied according to the load to be lifted. There are eighteen hydraulic rams on each side of the dock. These are 30 inches in diameter, and have a lift of 16 feet. The platform rises 2 feet for each foot of motion of the rams, so that the total lift of the latter is 32 feet.

The foundation consists of 72 cylinders of iron, which extend from the top girders below the mud-line. These cylinders are driven full of piles, none of which is less than 90 feet in length. This piling forms the true support, the chief purpose of the iron cylinders being the protection of the piles from the teredo, which is very destructive in the harbor of San Francisco. Resting on these foundation piers are a pair

of girders forming the sides of the dock. These in turn support the lifting-rams, each cylinder of which passes down between a pair of the piers. On the top of each ram is a sheave 6 feet in diameter, over which pass eight 2-inch steel cables. The total number of cables is thus 288, each of which was tested with a load of 80 tons. These cables are anchored in the bed-plate which supports the rams; thence passing over the sheave, they are secured to the side girders of the platform.

In lifting a vessel the load, of course, is not evenly distributed on the platform. It results that, while in operation, some rams may have full load while others have none at all. In order to maintain automatically the plane of the platform horizontal in spite of such inequality of load, a special valve-gear was designed as follows: Down each side of the dock a shaft is carried, operated by an engine in the power-house. At each ram this shaft is connected through a worm-gear and screw mechanism to the inlet and outlet valves. The valve-box moves up and down with the rams, the inlet and outlet pipes sliding in stuffing-boxes. The nature of the connection is such that if the shaft above noted remains stationary while the ram moves up, the valves become thereby closed and the motion stopped. On the other hand, if the rams are stationary and the shaft is turned, the valves are thereby opened and the rams put in motion. In operation, the engine controlling the shaft is started, the valves are thus opened, and the rams begin to move upward. The speed of the engine operating the shaft is so adjusted that for the rams which are moving at the slowest speed, that is, for those which are taking the principal load, the closing action due to their motion is just neutralized, and the valves just kept open. Should any of the rams less heavily loaded attempt to move faster, however, such increased speed results promptly in the closure of their valves, and a consequent check to the advance. In lowering, the motion is simply reversed, a like action of the valve-controlling mechanism preserving the platform horizontal, as in raising.

When the dock is up, a line of blocks on top of the foundations, 72 in number, are pushed under the platform by hydraulic power, and the platform is lowered on to them, where it remains until the vessel is ready to be floated again.

The construction of this dock occupied about one and a half years. From June 15, 1887, when the first vessel was lifted, till the end of 1892, there has been lifted a total of 689 ships, aggregating a tonnage of 719,819, or an average of about ten vessels per month.

For raising small vessels out of the water, the marine railway may be used. This consists briefly of a cradle for the support of the vessel, sliding on permanent ways, which, at high tide, extend into water sufficiently deep for the vessel to be floated into position over the cradle. The latter is connected through chains to a winding drum, by means of which cradle and vessel are together hauled up the ways and out of the water.

BUILDING-SLIPS.

The location of building-slips and their general direction with reference to the line of the water front are matters which depend chiefly on local conditions. The preparation of the ground for the support of the weight of the vessel is a matter which may require careful attention. If the site is on made ground, or if the substrata are largely mud, the site will require piling in order to safely take the weight of the vessel. The preparation of the blocks, staging, etc., as usually carried out, calls for no especial notice. We may, however, in this connection call attention again to the permanent staging at the Union Iron Works, as previously described in connection with travelling cranes. Three building-slips are thus provided with staging and cranes, each one being a skeleton building provided with complete means for the manipulation of the structural material while under the process of incorporation into the ship, together with all necessary means of access from without to the structure within.

The use of dry-docks as building-slips is also by no means uncommon. The advantages consist of less lifting of structural material, the possibility of a greater degree of completion before floating, and the absence of expensive launching operations. The disadvantages consist of greater first cost, with a darker and generally less agreeable place for the carrying on of the work.

(c) MACHINE ELEMENTS AND OPERATIONS.

The structural elements of machinery and boilers, as well as the operations necessary upon them, are the same in general classification as those already noted in (a).

(d) MACHINERY, APPLIANCES, AND METHODS.

Taking first the boiler-shop, and assuming that Scotch or locomotive boilers are to be built, we find the tools somewhat similar to those used in ship construction, which is but natural from the similarity of the material worked upon. Due, however, to the greater thickness of the plates, and to other details of the work, the tools must necessarily differ in many points.

Drilling.—Boiler-plates require pickling, planing, drilling, reaming, tapping, bending, flanging, and riveting. The appliances suitable for pickling and planing are similar to those used for like purposes on ship-plates. For drilling and reaming holes in flat plates, also, similar machinery may be used. For drilling, reaming, and tapping holes in the circular shell of the boiler, special tools are found desirable. One type of tool for shell drilling consists of two or three standards carrying a cross-head equal in length to the longest boiler to be handled. This cross-head has a vertical motion on the standards, and carries a number of drill-heads which have a longitudinal motion upon it. Each drill spindle has also a swivelling motion in a plane at right angles to the length of the cross-head. The shell to be operated on rests upon or is secured to a bed alongside the standards, and it is evident, from the combinations of motion provided, that radial holes may be drilled in shells of any diameter within the capacity of the machine, and at any point in the length. A narrow longitudinal strip only of the boiler can be reached at one time, however, and the shell must therefore be turned on the bed in order to bring all portions within reach of the machine. This is usually effected by means of the bridge crane, with which the shop should be provided. For similar operations on the heads the same or similar machinery is used. In other types of this machinery the shell is worked standing upright, or on end. In such cases the standards are usually two in number, with independent motions on the bed-plate. Each standard

is provided with its own drill-head, which has simply a vertical motion on the standard. The same machinery is also used for the insertion of screw-stays in boilers and stud-bolts in various parts of the engines. Many tools of this type are provided with a bed-plate borne on a spindle, by means of which the boiler is readily turned about a vertical axis, for bringing successive parts within range of the drills. In such tools it is necessary to allow to the standards a slight adjustment about the central spindle in order to assure that both drills may work simultaneously, even though the holes in question may not be located in the same diametral plane.

Bending.—For the bending of boiler-plates, rolls similar in general to those for ship-plates are used. Boiler-plates are in general thicker and smaller than ship-plates. Comparatively short but strongly geared and powerful rolls are therefore needed. From the greater ease of general manipulation and less floor space occupied, the vertical boiler-plate bending roll has come into quite general use. Such rolls should have a height in clear of from 8 to 10 feet, and be capable of handling plates of from one and a half to one and three quarters inches in thickness.

A type of vertical bending roll in use at Newport News possesses certain peculiarities which may be noted.

Instead of driving two rolls and letting the third revolve by friction, all three rolls are driven, the side rolls having a certain amount of lost motion introduced to allow for the calendering action. The work of driving is thus thrown mainly on the bending roll, which is appropriately geared; and although the pinions on the side rolls are thus relieved, entirely or in part, of the work of driving, they are always in readiness to assist, should the friction of the driving roll be insufficient. The side rolls being adjustable rather than the middle, makes possible the disposition of the principal train of driving gear in a more substantial manner. These rolls handle plates 10 feet wide and one and a half inches thick. The bending roll is 18 inches and the side rolls 15 inches in diameter. The side rolls are adjustable to and from the main roll, each end independently, and are controlled by an independent pair of engines. The weight of the tool complete is about 35 tons. Some builders prefer a hydraulic bending tool similar to the keel-bender, rather than rolls. This has the advantage

of working to the extreme edge of the plate, and of readily shaping short lengths, such as butt-straps, etc.

Flanging.—For flanging, boiler-plates are worked hot. The appliance in common use is the hydraulic flanger. This consists of two or three flanging heads supported by and contained in an appropriate frame, with base-plate for holding the variously formed anvils and dies. Two of the heads work vertically and one horizontally. One of the vertical heads is for holding the plate firmly on the anvil, while the other two, either singly or together, may execute various flanging operations upon it; or by means of appropriate punches and dies, small or moderate-sized flanges may be completed at one stroke. The necessary heating of the plate is usually carried out on an ordinary open fire, though gas furnaces have been used to some extent, and have given the best of satisfaction.

Riveting.—For the riveting of boilers there is probably no question of the superiority of machine over hand work, both as regards speed and quality. For the operation of machine-riveting tools, hydraulic power is in most common use. Steam or mechanical means, either by direct pressure or by hammering, have been used to some extent, but in modern tools hydraulic power has practically no rival. In some riveters the pressure is taken wholly upon the rivet; in others, pressure is first brought to bear upon the plates, thus firmly closing them together. The rivet is then acted on in the usual way, but with a lighter pressure than when it receives the whole load. A given amount of total pressure subdivided in this way is believed to give better results than when wholly expended on the rivet. Hydraulic riveters may be divided into the two classes of portable and stationary, or what is equivalent, shallow and deep throat. If the joint is near the edge, the shallow throat is sufficient, and there is no reason why the tool should not be made light enough to be readily portable. For joints far from the edge the riveter is necessarily so heavy that it must be stationary. The modern tendency in boiler construction seems toward the more complete elimination of the element of hand labor. This is in keeping with the general tendency in industrial work, and is rendered the more necessary by the increasing size and thickness of the plates employed.

Machine Tools.—Passing next to the machine-shop, it is plain,

without noting in detail the various operations required by different parts of a marine engine, that the equipment will require planers, slotters, lathes, boring-machines, drills, milling-machines, etc., together with means for transportation and handling. In addition to these standard tools, various special tools for particular purposes may be provided. Among such may be noted the following: Multiple drills for condenser tube-sheets; special lathes or attachments for fitting up crank-shafts; special forms of planers and saws for planing and cutting armor-plate; special forms of boring-mill for boring the flanges of shaft-couplings in place, etc.; vertical drilling, tapping, and stud-inserting machinery, similar to that mentioned in connection with the boiler-shop, and adapted to a large variety of work on cylinders, valve-chests, etc.; horizontal or vertical boring and milling machines combined for various forms of boring, surfacing, and fitting; special forms of planer with combination motions, so that five sides of a piece of generally rectangular shape may be worked on without moving the piece on the bed; emery grinding and polishing machinery for rough grinding on castings, etc., and for grinding and polishing propeller blades. Mention may also be made of a proper form of furnace for the heating of the parts of built-up crank-shafts.

The size and capacity of such tools will depend wholly on the nature of the work to be carried on, but if modern engines of large size are to be constructed, planers of sufficient size to handle the bed-plates, frames, etc., will be needed. The lathes must handle line and crank shafting of 20 inches or two feet in diameter, with various other parts in proportion. The boring-mill must admit cylinders of 100 inches and upward in diameter, and other appliances must be on a similar scale.

The appliances for transportation and handling have already been noted. Here, as elsewhere, the tendency is toward the elimination of hand labor, and also toward the development of such tools and methods as shall admit of doing the maximum amount of work, both as regards extent and variety of operations, without moving the pieces. The latter, especially, tends toward accuracy of work, since with no shift of the piece the only errors introduced in passing from side to side will be those of the tool itself, and these should be

negligible. All the work so done in one position should then be square, true, and in line.

(*e*) ARRANGEMENT AND POWERING.

An examination of the processes and tools noted in the previous sections will show that in general we must have the following shops or places where such classes of work may be done.

For Hull Work.—(1) Cold-bending, rolling, drilling, punching, shearing, reaming, planing, etc.

(2) Forging and general blacksmith work.

(3) Frame bending and proving.

(4) The assembling and fastening, temporary or otherwise, of various structural members of the ship.

(5) Mould loft.

(6) Wood-working shop.

For Engines and Boilers.—(7) Machine-shop or engine-building and general machine-work.

(8) Boiler-shop.

(9) Foundries for iron and brass.

General.—(10) General rigging, outfitting, and painting.

(11) Power plant.

The exact solution of the problem of the best disposition of these shops is one which, perhaps more than any other, gives opportunity for differences of opinion. The special circumstances of any given case must necessarily have much weight, and may justly lead to quite a different arrangement from that indicated by general principles.

As one of the fundamental principles bearing on the question of the arrangement of a plant, we may assume that any given piece should, as nearly as may be, travel on a straight line on its way through the course of preparation, and that this line should have the minimum number of intersections, with similar lines for other pieces. We may also say that, as a whole, due regard should be had for both economy and speed.

Unfortunately, the problem is much complicated by the necessity that one machine shall do work on many different kinds of pieces, that one unchanged routine cannot always be followed, and that an arrangement which might be ideal for one class of work might present grave inconveniences for

another. It also seems true, within certain limits, that the arrangement which might be suitable for maximum economy might not at the same time provide for the best speed, and *vice versa.* There is, therefore, for ship-yard tools, no one scheme of arrangement and powering which can unhesitatingly be pronounced the best for all circumstances and classes of work. Due, however, to this very character of the problem, and to the difficulty of studying the effects on speed and economy of production, of varying combinations of arrangements, it is probably safe to say that no yard has yet attained to a truly ideal scheme of arrangement and powering, and therefore that each one is susceptible of improvement in various particulars, if only such particulars could in all cases be definitely specified.

The operations classed under (1), (2), (3), and (4), above, being those chiefly concerned with the construction of the hull, form one principal group. The buildings or places provided for these operations should therefore be near together, and with ready means of communication between them, especially from (1), (2), and (3) to (4), and from (4) to the building-slips. The stock should also be distributed conveniently to (1), (2), and (3), and as close as possible to the machines to which it is to go first.

Under this head, reference may be made to a new framing shed recently erected at the Newport News ship-yard. This shed is 344 feet long on the water-front side, 272 feet deep, and contains general frame and plate machinery. Running the entire length of the centre of the building is a continuous platform, on which can be fitted up at the same time six frames for vessels of any size up to 70 feet beam. After the material for a frame is assembled and properly fitted together on the platform, the frame is run off complete to the riveting floor, which extends the entire length of the water-front side of the shed. Here it is riveted up by hydraulic machinery, after which it is placed upon a truck which runs on a track across the entire front of the building-slips. By this means the frame, ready for erection, is delivered to the cantilever crane, by which it is transported to the proper point and erected in place on the keel. The roof of this framing-shed is traversed from side to side every 15 feet with continuous I beams, on each of which are two or more four-wheel trolleys.

These support hooks or chain hoists, and thus furnish every facility for transportation from side to side. For the support and manipulation of the hydraulic riveters, three hydraulic pillar cranes are provided. Each boom has about 60 feet reach, and thus the length of one side of the shed is completely covered. The riveter itself is supported by a chain hoist from a trolley, the latter having motion along the boom. The boom as a whole may be swung horizontally into any desired position, and at the same time raised or lowered through its connection with the pillar and the hydraulic cylinder.

For the location of the other shops as mentioned above, the principal considerations are perhaps the following:

The power-house, other things equal, should be located in a central position, and this may indicate the location of those shops where the most power is used in such positions that, considering the entire ground covered, the power-house may be fairly central, due regard being also had to possibility of extension, and to ready means of intercommunication where it may seem desirable. There is usually much running to and fro between ships at the docks or in the fitting-out basin and the outfitting-shop. To reduce this to a minimum the outfitting-shop should be located as near as may be convenient to the docks and basins. For the storage of paints, oils, turpentine, etc., the use of a separate building seems very desirable. As installed at Newport News, all such materials are stored in tanks contained in a separate building, into which no one enters except for the purpose of replenishment. Pipes lead from these tanks to the paint shop, by means of which the various materials may be there drawn as required.

SUBDIVISION AND DISTRIBUTION OF POWER.

The provision of power to a ship-yard presents this problem: To supply power of variable amounts and for variable times to various machines and tools scattered over an area of, perhaps, several acres. This problem may be solved in two chief ways:

(1) The use of one centrally located prime mover, from which by various means the power is conducted to the different shops or places where its use is desired.

(2) The subdivision of the power required into a number of units of the same or different amounts, each unit being

developed ultimately by an independent prime mover centrally located with reference to it. The size of the subdivided portions may vary from the power necessary to drive a whole shop to that required for a single machine; and, in fact, the case of undivided power is simply that of one unit including everything.

Coal and other carbon compounds form practically the only ultimate source of energy at present commercially available, and the heat-engine is the only practical means at present of utilizing this energy. Of heat-engines, the steam-engine is the most important, and it may stand as representative of the class.

The development of mechanical power from coal involves two steps:

(1) Its transfer from the coal to the steam.

(2) Its transfer from the steam to the mechanical energy in the engine.

The question of subdivision may therefore be considered in relation to both engines and boilers.

The advantages in the subdivision of boilers are: (1) The saving of piping. (2) The saving of condensation in long lines of piping. (3) The somewhat greater degree of safety against disability from breakdown.

The chief disadvantages are: (1) Greater first cost of boilers and settings, chimneys, boiler-houses, pumps, attachments, etc. (2) Greater cost of attendance. (3) Probably less efficiency in themselves.

Unless the distances to be covered are very considerable, there would seem to be a balance of advantage in favor of the centrally located boiler plant; and at all events, there need be no great difficulty in so locating the shops where most of the power is needed that they may be served from a single battery of boilers.

Assuming for the present, therefore, a single boiler plant, we may next inquire as to the various methods of delivering the power thus developed to the various points where needed. For such purposes as we are here concerned with, there are four chief means of transporting energy: (1) Mechanically. (2) Electrically. (3) By compressed air. (4) By hydraulic means. If we trace the energy along step by step, we note that it undergoes a series of transportations and transforma-

tions, the nature and order of which depend on the particular means employed. For the four cases noted, these may be illustrated as follows :

(1) Boiler—Pipe—Engine—Mechanical transformation—Work.

(2) Boiler—Pipe—Engine—Mechanical transformation—Dynamo—Wire—Motor—Mechanical transformation—Work.

(3) Boiler—Pipe—Engine—Mechanical transformation—Air-compressor—Pipe—Air motor—Mechanical transformation—Work.

(4) Boiler—Pipe—Engine—Mechanical transformation—Pump—Pipe—Hydraulic motor or press—Mechanical transformation—Work.

In case (1) if the pipe is short and the mechanical transformation long, we have the centrally located prime mover. If the pipe is long and the mechanical transformation short, we have the case of power subdivided among several engines, each located near its own work. We will first note the relative advantages and disadvantages of these two cases :

In the latter we may note as advantages :

(1) Each engine is run when and only when it is needed, and admits of a variable speed to suit possible variations in the nature af the work.

(2) There need be but slight loss in efficiency due to wide variation in the total power called for, as is the case when the whole power is derived from one central engine. The loss in efficiency due to variation of load is too well known to need detailed examination. It is of especial importance where the work required is widely variable in amount, as is the case with ship-yard work. If a considerable portion of the works are run by one engine, its capacity must be sufficient to supply the maximum demand for power likely to be made, and the average efficiency of such an engine, used under conditions frequently varying between one quarter and full power, may well be reduced 25 per cent below its maximum value.

(3) There is but slight loss from mechanical transmission. The loss in running long lines of shafting and the corresponding belting is frequently greater than may be supposed. Such loss is rarely at its minimum value. The shafting tends to get out of line, belts become stiff, and are frequently laced with an extreme tension. It is no exaggeration to say that, in

a plant spread over considerable area, 20 to 40 per cent of the power may easily be absorbed in mechanical transmission.

(4) A breakdown affects only the tools served by the particular engine disabled, and this admits of ready repair by keeping in hand a set of spare parts. The advantage in this respect is much increased if the various engines are of the same make and size, in which case we have a complete interchangeability of parts. Usually this is not entirely feasible, especially when it is proposed to run certain of the heavier tools each with its own engine. In any event, however, the engines should be kept as nearly uniform as possible in type and size, in which case the number of spare parts necessary to provide against accident will be reduced to a minimum.

(5) Where tools are driven by separate engines, line-shafting and belts are avoided, thus giving much better opportunity for the operation of cranes and overhead trolley transportation. The various tools may also be set, each in that particular place and direction best suited to the nature of its work, irrespective of its relationship to a line of shafting.

(6) The general system of a duplication of engines admits of a gradual increase in power as needed, and thus provides for indefinite expansion.

(7) In the matter of first cost there is no great difference, or rather the cost per horse power will depend quite as much on the type and make of the engine as upon the size.

(8) In the matter of liability to derangement, deterioration, cost of repairs, etc., much depends on the engines themselves and upon the care they receive. With equally good construction and equally good care, it is not likely that there would be much difference in this particular.

As disadvantages, we may note the following:

(1) The supervision required may cost somewhat more than with central plant, though this will depend much upon the special circumstances. In many cases where subdivided power is used, the actual number of engineers is not increased. The stopping and starting are looked after by the foremen of the various shops, or by the men in charge of the special tools. The engineer proper is then able to give to these engines the usual attention necessary for their efficient action, and to make such repairs as are from time to time necessary. Great improvements in self-lubrication have, moreover, been

made in the types of engines suitable for subdivided power plants, so that the amount of routine attention required is reduced to a minimum.

(2) There will be loss of steam through condensation in long lines of pipe. The loss of heat from a naked pipe in still air takes place in two ways—by radiation and convection. Both losses increase rapidly with the temperature difference, that due to convection being approximately one and a half times that due to radiation. The high importance of these losses may be appreciated from a statement of its amount for one set of conditions. A naked steam-pipe in air carrying steam at a pressure of 100 lbs. will surrender per square foot of surface an amount of heat approximating closely to 650 B. T. U. per hour. This entails the condensation of somewhat more than one half-pound of steam per square foot per hour. If instead of still air on the outside of the pipe we have a stream of running water, the loss of heat is enormously increased. We have in fact simply a surface condenser, with its well-known efficiency for the abstraction of heat. In the conveyance of steam through underground pipes the presence of water on the outside, either still or running, is therefore to be most carefully prevented. By the use of hair-felt or other non-conducting covering the loss in air may be reduced to from $\frac{1}{8}$ to $\frac{1}{10}$ of its amount for a naked pipe. The most satisfactory method for the conveyance of steam to considerable distances under ground is therefore to construct first a tunnel or subway water-tight in itself, of sufficient size to carry the necessary pipes, and to admit the passage of a man for their examination. Within this subway the pipes, well protected by non-conducting covering, will carry steam with but slight loss to distances greater than any likely to be met with in ship-yard equipment. This method is, of course, expensive in first cost, but the saving effected and the availability for repairs seem to well justify the additional expense.

If the water-tight subway cannot be afforded, the following method, which has given excellent results, seems the next most desirable. A ditch of the necessary depth is prepared, at the bottom of which is laid a line of ordinary drain-tile for the removal as far as possible of the soil water. A bed of concrete is then prepared, in which is laid a box made of

planks. In this box the piping is laid, well protected by non-conducting covering, the cover is nailed on, and fresh concrete is placed over the whole. The box is thus entirely surrounded by concrete, which serves as a protection against the water, while the non-conducting covering on the pipe itself reduces the loss by radiation.

(3) The economy of a small engine, other things being equal, is somewhat less than a large engine. This is true in general, but great improvements in recent years have been made in the economy of small engines, so that now compound engines of excellent economy may be obtained of sizes to suit any ordinary set of conditions.

(4) The preparation of foundations and the setting of a large number of small engines may or may not be more expensive than the same operations for a few large engines, as determined by circumstances. Among the various improvements in engines suited to subdivided power plants, much has been done toward making the engine self-contained, and thus largely independent of special foundations. With such engines of moderate size, transportation and erection are greatly simplified, and the combined cost of foundations and erection may well be less than that for a single engine of equal capacity.

We may next note the points connected with the modes of transmission referred to in (2), (3), and (4).

In (2) and (3) the object in view is the more ready or effective transfer of the energy to considerable distances, while in (4) it is rather a transformation looking toward an exchange of speed for power, in order the better to adapt it to the performance of certain operations. It is true that hydraulic-pressure engines used as prime movers for ordinary machinery have been by no means unknown; but such uses are now rare, and for shipyard purposes the use of hydraulic power is restricted to the purposes mentioned above.

In (2) and (3) it may be noted that for the actual transportation the mechanical energy of the engine is transformed, in one case into a type of ethereal energy, and in the other into the energy contained in air under compression.

The advantages of electrical distribution are:

(1) But slight loss of energy by the wire, even when the energy is conveyed to great distances.

(2) The ease with which the energy may be conducted along tortuous paths from the source of supply to the various points where its use is desired, and the readiness with which this use is effected, either at a stationary or moving point.

With compressed air as compared with steam, the chief advantage is in the absence of loss from condensation. This advantage becomes of very considerable amount when the distances to be covered are large, or when the energy is to be used temporarily at variable points, in which case the use of lagged pipes would be attended with some inconvenience. With hydraulic power, the chief advantage lies in its availability for special forms of work as noted above.

The chief disadvantage of these methods of distribution as compared with steam, is in the losses of energy which are necessarily connected with the various transformations. Such losses are, however, inherent in all modes of distribution, and their chief characteristics may be noted in common.

In general, we may assert that whenever energy is changed in form, or whenever actual energy is transported from one point to another, a certain portion of it is lost, such loss usually occurring as heat. In other words, energy is a commodity so fugitive that we are not able to handle it in any way without thereby occasioning the loss of a certain portion. Furthermore, when energy is in the form of heat, there is a constant loss or degradation of availability, for in no way can we completely insulate heat as such.

Referring to the schedule of operations, we note that, starting in each case with the boiler, we have in (1) a loss in transmission through the pipe, a loss in transformation in the engine, and a second loss by transmission through belts, shafting, etc. Taking the two cases under which this mode was discussed, we may consider the following statement of losses as illustrative of the points of difference:

	Loss (1).	Rem.	Loss (2).	Rem.	Loss (3).	Rem.
Engine-power not subdivided	5%	95%	83%	16%	10-30%	14-8%
Engine-power subdivided	10-30%	90-70%	86%	13-10%	5-10%	12-9%

These figures would relate more especially to steady work. With wide variations in the work, the relative efficiency of the subdivided system would be comparatively better. It seems probable, however, that, so far as efficiency alone is concerned,

the difference need not be of very great importance, so that the extent and nature of the subdivision must be determined rather by such other considerations as were noted in the discussion of these points.

Turning next to the losses which arise from the uses of compressed air and electricity, it is seen that there are four losses by transmission and three by transformation. If these various losses are summed as above, we shall find that from 5 to 8 per cent of the energy in the steam may be delivered, by electrical transmission, to the point of consumption, while a somewhat less amount, probably from 4 to 6 per cent, may be similarly delivered by compressed air. These final efficiencies are less than those noted above for steam and mechanical transmission; but it must be remembered that the distances assumed are very much greater, and that with such increased distances the efficiency of the steam-mechanical mode would fall below the values for either air or electricity as the mode of conveyance.

The case of hydraulic transmission is similar to the last two, and the losses occur in a similar way. The chief difference in this respect is in the very considerable frictional loss which is necessarily connected with the operation of hydraulic machinery. This reduces the final utilization to a point somewhat below that for compressed air or electricity. When, however, we consider the very perfect adaptation of hydraulic power to the production of very great pressures acting at low velocities, any slight decrease in efficiency, viewed as a disadvantage, falls into insignificance.

When we consider the nature, number, and location of the various operations carried on in a shipyard, it is quite evident that the use of subdivided prime movers is appropriate to the case. The exact amount and nature of the subdivision, the form under which it is transmitted, etc., depend much upon the particular circumstances, and only general principles can be laid down. The engineer has at his command, for the attainment of any given result, the time and power of man, the powers of nature, and the materials of construction; and it is evidently his duty to use such combination of these as will represent the minimum total expense, proper regard being had to durability and permanence of plant. Furthermore, from the preceding principles, and considering that matters

relating to handiness and general adaptability for use are equal, it follows that, between the coal and the work to be performed, there should intervene the minimum number of transformations and transmissions. Hence, other things again being equal, we should use the steam-engine as prime mover with the minimum amount of transmission admissible. This points to subdivided engine and boiler power.

The indefinite multiplication of engines and boilers over a yard is, however, hardly desirable, and for temporary uses of power at variable points the use of steam is accompanied with many disadvantages. If, furthermore, the multiplication of boilers is avoided by the conveyance of the steam to considerable distances through pipes, serious loss by condensation results. It is for all such cases of use at great distances from convenient development, or for temporary use at variable points, or for special purposes for which it may have peculiar adaptability, that the methods of carriage by compressed air or electricity are available, with the various advantages which have been already stated.

In connection with the modern extension of the electrical transmission of power, and of the use of electric motors as immediate prime movers, it may not be out of place to give warning of the possibility of carrying such application to an extreme not justified by the partial advantages which may seem to be gained. In all such cases of rapid growth into popularity there is a tendency toward unjustifiable extremes; and, in the case mentioned, such extreme certainly exists, and in certain directions would seem not far removed from present tendencies. It must not be forgotten that electricity is neither a source of energy, nor, as at present developed, even the result of a single transformation from a source. The use of an electric motor entails a preceding series of transformations, all involving losses of varying amounts, and due to which, so far as mechanical efficiency alone is concerned, the justifiable limit will soon be reached. It follows that the use of an electric motor at any given point instead of a steam-engine at the same point, or power from a steam-engine transmitted mechanically over moderate distances, will involve a very questionable advantage in mechanical efficiency, and may readily involve a loss in this respect. It should, therefore, be clearly understood that in

such cases the use of electric motors can only be justified by superior adaptation to the work in question, and that unless such superiority is well pronounced, the advantage of electric motors may be considered doubtful. Such general adaptation in this case, as well as in all others arising in the problem of the proper subdivision of power, includes considerations of ease of manipulation, readiness of adaptation to varying conditions, safety against extended stoppage in case of breakdown, capacity for extension, interference with transportation, etc.; and all such considerations, as well as that of efficiency, should receive due weight.

As an example in point, the equipment of the individual tools of a framing and plate shed or boiler-shop with independent electric motors would almost surely result in a lower efficiency than would result from the use of steam-engines, either individual or in large units. Unless, therefore, electric motors possess a greater superiority in general adaptation and handiness than seems apparent, their use in such case would be ill advised. On the contrary, for many other cases which have already been mentioned, their superiority of adaptation is so great, that no doubt can exist as to the advisability of their use.

In the application of these general principles, the power required may be supposed divided into an appropriate number of units, as nearly equal and as nearly constant as may be, each such unit to be driven by a steam-engine. The shops requiring such power should then be placed as near as possible to the central boiler-house. Various tools and appliances will then require individual prime movers, either steam or electric, as the case may need. For such electric requirements, including the operation of bridge cranes and hoists, electric welders, and the provision of temporary power at variable points in the shops, or the general provision of power at ships under construction or repair, as well as for the provision of light throughout the yard and shops, a central electric station will be required. If, in addition, the use of compressed air is desired, the necessary compressors, located at any convenient point, must be provided. As already noted in a previous section, it seems quite possible to substitute electric power for compressed air in the few cases in which the latter is at present used. Such substitution is not

desirable on the score of efficiency or adaptation, but rather because it would result in eliminating the pneumatic service entirely, with its first cost and cost of maintenance, and thus unify the entire supply of power for the purposes mentioned, under one system. Even if the efficiency were less, or the adaptation slightly inferior, the substitution would still seem desirable.

For the operation of the various hydraulic tools, the necessary pumps and accumulators must be provided, the various locations being so arranged that the intermediate piping shall be a minimum.

While general principles may thus be laid down for the powering of a ship-yard, yet their application in any given case must involve a very considerable element of judgment, such judgment being the more reliable the broader the experience on which it is based.

The same is true in general for the equipment of the yard as a whole; and while there is certainly some one combination which would result in the best all-around efficiency as a ship-producing plant, yet it is equally sure that we have no sufficient data on which to form exact ideas of what such combination for any given case should be. General efficiency in such case is a quantity so complex and so obscurely related to the quantities involved, that we can never expect to attain, without experience, even to a measurably correct result. Such experimental data are in large measure lacking, especially with regard to the tools and appliances which represent modern tendencies in ship-yard equipment. This is but natural from the very nature of the case; for experimental determination of the general efficiency of ship-yard equipment would involve experiment on too vast a scale to admit of serious consideration. While, therefore, we may have confidence that present tendencies are toward economy and better efficiency, yet we are not able to state with any closeness of approximation the general efficiency to be expected in any given case, nor even with confidence the particular combination of equipment which in such case may be expected to give the best result. If it were not for the vastness of the scale, special studies on the general efficiency of such large industrial plants would seem highly desirable.

In any event, a given case must be studied in the light of

such experience as is available, be it small or great, and of such general principles as seem applicable. Such study tempered with judgment will lead to a result which we may well believe will be not far wrong, even should it be slightly different from that which would have been indicated by a more complete knowledge of the fundamental data.

DISCUSSION ON THE PLANNING AND EQUIPMENT OF MODERN SHIP AND ENGINE BUILDING PLANTS.

MR. GEO. W. DICKIE:—I did not expect to be called upon to speak at this session; in fact, I had come quite prepared to enjoy to the fullest extent the fine views that Prof. Durand has prepared for the purpose of illustrating the very important subject treated of in his paper.

Since Prof. Durand has called upon me to describe certain parts of the equipment of the Union Iron Works, I have no choice but to accept such a kind and complimentary invitation.

The view that is now shown of the staging and cranes over the building-slips at the Union Iron Works will serve very well for the purpose of making a comparison between the methods that we have adopted for the handling of materials entering into the construction of a ship being built, and the arrangement which Prof. Durand has shown, and described in his paper, for the handling of materials during the process of construction of a vessel at Newport News.

In that case a crane with arms extending out on each side of sufficient length to take in a ship of the greatest beam, traverses an elevated track placed between the vessels that are being built. This elevated track traverses a distance equal to or greater than the length of the vessel.

When constructing a vessel on each side of this elevated track, the crane is supposed to serve the one vessel with one arm, and serve the other vessel with the other. Suppose that both of these vessels were being plated at the same time, and a plate was required to be placed under the starboard quarter of the one vessel and under the port bow of the other: it is very evident that the crane would have to serve the one place before it could be available for serving the other, and as both sides of each vessel are being plated at the same time, as a rule, there are four plates required to be handled at the same time, in order to go on uninterruptedly with the work. The weak point in the crane at Newport News appears to me to lie in this, that while it is supposed to be able to

serve both sides of two vessels, it can only be working on one side of one vessel at any one time.

As we have it arranged at the Union Iron Works, over each slip is erected a skeleton frame, the side supports of which carry all the staging, while the roof-trusses that span the slip carry two cranes travelling the full length of the vessel. The support for the centre ends of the cranes is placed from two to three feet from the centre of the roof-truss, so that one of the cranes always commands the centre-line, while the other is slightly short of reaching that point.

The advantage of this system is that each side of the vessel has an independently operated crane entirely devoted to the service of that side, while the other side of the vessel has a corresponding independent crane that can be used at any point.

If we compare the service available at the Union Iron Works for two ships compared with two ships at Newport News, we find that in the Union Iron Works, if two vessels are in course of construction side by side, the cranes can be at four points at any one time, while at Newport News the crane can only be at one point at any one time.

One thing that must be borne in mind in connection with travelling cranes for handling material of ordinary weight, such as ship plates, which have to be secured in position by service-bolts before the crane can be available for any other work, is that the time occupied in lifting and traversing the work into position is, as a rule, only a fraction of the total time, the greater portion of the time being consumed in holding the work in position until service-bolts are in place.

The view given here of the hydraulic-lift dock at the Union Iron Works gives a very fair idea of the appearance of this dock.

When the question of providing a dry-dock in connection with the works came to be discussed by the Directors of the Union Iron Works, the form and type of dock that would be the proper thing to build in connection with the works was a matter of very long and serious debate.

The ground available on which the dock would require to be built consisted of a flat bed of mud about one hundred feet in depth, and upon which there was at high tide about twenty feet of water.

I had had for years in my mind the construction of a hydraulic-lift dock for general use in San Francisco Harbor. A large portion of the work for which the dock is used in San Francisco is cleaning and painting. I had observed the difficulties in connec-

tion with this work done on a graving-dock, the length of time that it took to get the bottom of the vessel dry, and in condition for painting; and I reasoned that if the vessel could be lifted up out of the water instead of the water being pumped away from the vessel, and if there was an opportunity for the wind to have full access to the whole of the bottom of the vessel, that much better work could be done in a day under these conditions than could be done in two days in the graving-dock.

The nature of the ground presented great difficulties in the construction of an inclosed dock. It was decided, after much thought had been expended on the subject, to built the hydraulic lift-dock as I had designed it.

Work was commenced on this dock in the beginning of 1886, and the dock was finished in June of 1887.

The description of this dock in Prof. Durand's paper gives a very good idea of its construction.

We have lifted very close to one million tons of shipping, and without any accident whatever either to the vessels lifted or to the dock itself.

The cost of operating this dock is considerably less than that of operating the graving-dock. The smaller the vessel to be docked in a graving-dock, the larger amount of work that has to be done by pumping, while in the lift dock the work to be done is practically in direct proportion to the weight of the vessel to be lifted. Consequently the expenditure bears a direct ratio to the revenue, so far as the power for operating the dock is concerned.

A peculiar feature in connection with this dock is the controlling gear that operates the valves admitting water to and discharging water from the rams. This is a distinctive feature of this dock, as compared with Clark's Hydraulic Lift Dock, the operation of which and the preservation of alignment depending entirely upon the skill of the operator; whereas in the dock of the Union Iron Works the whole operation is automatic, and the alignment of the platform upon which the ship rests is entirely independent of the position or the amount of the load at any one point.

From the fact that a larger amount of work can be done in a given time with the same number of men on this dock than in the graving dock, it has been from the very start exceedingly popular with ship owners, so that vessels very much prefer to use the lift-dock.

The capacity of the dock admits of a ship being lifted whose length is equal to the dock, and having a displacement of 4400 tons.

The hydraulic bending-press shown in the picture now on the screen has been found a very useful tool in our yard. It has a capacity for exerting a pressure of 200 tons. It can take in a plate 14 feet wide between the side standards, and has a vertical movement of 36 inches.

The work under the press shown in the picture is one of the sponsons between the berth and gun decks of the "Olympia," and is of 2¼-inch plate. This plate is being bent to a curve of 18 inches radius, the plate being 7 feet in width. This work is being done cold. Nearly all the shaping of plate-work at our yard is done cold on this press. Garboard strakes, stern tube-plates, and all plates having irregular bends are shaped on this machine, and all of the work is done without special formers; in fact, we have found that a man who understands thoroughly the shapes required can turn out much better work from this machine without formers than with them.

The large wall planing-machine now shown on the screen has just been completed and put in operation at the engine-works. The heavier portions of this fine tool were made at the Union Iron Works. The bed-plate is level with the floor, and serves to some extent as a laying-off floor for heavy work. It is 33 feet in length and 18 feet in width; composed of cast-iron sections 3 feet in depth, and resting on a solid concrete foundation. The traverse of the planing-head is 25 feet horizontally and 18 feet vertically. This is a fine example of the side planer, and enables us to do all the facing work on large pieces without their being moved, and while other work is going on upon them at the same time.

In preparing for doing the machine-work on large pieces, I think it is wise to avoid as far as possible moving such pieces on heavy platens while the work is being done. If such large pieces are in motion when work is being done by tools upon their surfaces, there is not only a large loss of power required for the work when done in this manner, but while it is being done other operations, such as drilling and fitting, are suspended, and consequently loss of time is the result from such practice.

The side or wall planer is not a very familiar sight in the shops of this country; but there is no doubt that, as we advance in the manufacture of engines of high power, such machines will become more general than they are now.

THE CHAIRMAN (Engineer-in-Chief MELVILLE):—I want to add just a word to Mr. Dickie's comments on Professor Durand's paper, to express my appreciation of its value, and also the pleasure that I know all of you have felt with myself in witnessing this

admirable series of lantern views, and hearing the professor's comments.

I may say that Professor Durand undertook this paper with some hesitation and at my personal request. He thought that it would have come better from some manager of a large ship and engine building works; but I persuaded him that his recent visit to Europe, where he saw a great many of the leading establishments, as well as his visits to some of our own most important ones, put him in a position to discuss the problem very satisfactorily. I am sure that you will all agree with me that his analysis of the problem is admirable, and that his conclusions are of great value.

Like some of the other topics that have been treated before the Congress, there is nothing specially new in Professor Durand's paper; but he has grouped in a convenient form a great amount of valuable information, which I am sure will be of considerable value to any one who is planning an establishment from the beginning, or desires to improve one already existing.

A point which especially pleases me is the way in which the Professor has treated the question of the arrangement of the power for working the tools and other appliances. He has emphasized the importance of having this done systematically, and not, as is the case in so many of the older establishments, simply at haphazard, —putting in a new engine and boiler when some new shop comes along. He outlines the considerations which should govern us in the distribution of the power plant, and I feel sure that this will well repay careful study.

I am sure you will all join me in thanking the Professor for the way he has entertained us this evening.

PROF. DURAND:—I am under obligations to Mr. Dickie for so kindly supplementing my remarks in regard to the tools and appliances at the Union Iron Works, as indeed I am indebted to him for the opportunity of describing them at all.

I could hardly fail to feel flattered by the compliments of Commodore Melville, and I want to express my appreciation of them.

Finally, I thank you all for the attention given to my paper and to the lantern-slides illustrative of it, which is as great a compliment as an author can expect.

XXIX.

DEVELOPMENT OF THE ICE-YACHT ON THE HUDSON.

By ARCHIBALD ROGERS, Esq.,

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The climatic conditions during the winter months of that portion of the Hudson River from Newburg to Hyde Park, a distance of about twenty-three miles, is especially favorable, by reason of the sudden changes of temperature and precipitation which occur, for the exhilarating pastime of sailing over ice. For the reason that in this section there are more clubs and more yachts of different types, and that yachts of other localities are now either the same or modifications of those of the Hudson River, I shall confine this brief account to local experiences, which in fact it seems necessary to do, as the only other club of any importance away from this vicinity is the North Shrewsbury Ice-yacht Club, of Red Bank, New Jersey, and this enterprising organization has for years past sent its best yachts to compete in trials of speed with those hereabouts. The Orange Lake Ice-yacht Club must be included with those of the Hudson River, for, situated near Newburg, N. Y., the conditions of weather and sailing are much the same. That there are no other clubs or ice-yachts outside of what I have already mentioned would be unfair to state, for there are some scattered over the country. Lake Champlain boasts of a club or two; and recently two crack yachts of the Hudson River Club, the "Reindeer" and "St. Nicholas," were purchased to sail on the lakes near Minneapolis, and I am told that they have been successful there

in winning from all the local yachts. Probably one of these yachts will be exhibited at the World's Fair. The credit, though, belongs to the Hudson River clubs for the intelligence, skill, and persistent development which have evolved the present type of ice-yacht.

The principal clubs of the Hudson are as follows: The Carthage, with station at Carthage Landing, N. Y., possessing a fleet of 26 yachts, mostly of the jib and mainsail type, but some are cat-rigged, and one is a lateen—an uncommonly fast yacht, to which I will refer later on. The largest yacht has a jib and mainsail, and spreads 950 square feet of canvas to the winter breezes. The balance of the yachts would average in size about 400 square feet of sail area. New Hamburg Ice-yacht Club is one of the older organizations, and has 23 yachts enrolled, ranging in size from 900 square feet of sail area down to 250. Orange Lake Club, New York, claims 10 yachts, one of which is a large cat-rigged craft of 800 square feet of sail area. I will revert to this boat again, as she is peculiar. The Hudson River Ice-yacht Club, station Hyde Park, N. Y., which, without injustice to the others, I may style the leading club, possesses a fleet of 41 yachts of all types, jib and mainsail being the favorite one, however. The largest yacht has about 800 square feet of sail area, and the smallest 150.

North Shrewsbury Ice-yacht Club, station Red Bank, New Jersey, has 14 boats, averaging about 452 feet of sail area in size, and one larger yacht of 890 square feet of sail area.

All the clubs I have mentioned are progressive and active associations, controlled by the usual officers, such as commodore, vice-commodore, treasurer, and secretary, along with a regatta or sailing committee, whose duty it is to take charge of the racing.

The early yachts of the Hudson were constructed a good deal on the lumber-box order. They were heavy, hard-riding, and hard-headed too, generally jib and mainsail in rig, the mast set up over the runner-plank, and not some distance ahead, as prevails at present. They had short gaffs, long booms, moderate hoist, and big jibs. This stepping of the mast over the runner-plank gave the boats a bad balance,—that is, it brought the centre of effort too far aft and also the

weights; consequently the tendency in beating to windward was to luff, and this had to be avoided by keeping the boat's head off, and the weight of the mast being too far aft also brought additional pressure on the rudder. All this unnecessary friction caused a proportionate loss in speed, especially to windward.

This type of yacht reached its greatest development in the "Icicle," the largest ice-yacht ever constructed. She was built in 1869, and was improved and enlarged until she measured 68 ft. 11 in. long, with sail-driving area of 1070 square feet. She was unquestionably the fastest in 1879 of any of the yachts on the river. It was not long, however, before an improved type of rig and construction made its appearance, and this was accomplished by stepping the mast about three and a half feet further forward or ahead of the runner-plank. This necessitated shortening the jib, making it more of a balance sail than before. Main booms, too, were cut off and gaffs lengthened, bringing the sail more inboard, and thus placing the centre of effort in a much more proper relation to the centre of resistance. Side rails and cockpits gave way to wire guys with adjustable turn-buckles, and small elliptical boxes for the helmsmen.

To Mr. H. Relyea belongs the credit for this departure from the old type. He built the yacht "Robert Scott" in 1879, and the result was so satisfactory that she was quickly purchased by one of the wide-awake members of the Poughkeepsie Club, the pioneer Ice-yacht Club of the Hudson, which is now, unfortunately, for all practical purposes, disbanded. The "Scott," under a changed name, easily outpointed and outfooted her rivals and won many victories, and was able even to win from "Icicle," whose sail area was twice as great, "Scott" having but 499 square feet. She was not to have things all her own way, for in 1883 "Jack Frost," a yacht similar in type, but larger and more powerful, came out and proved the faster boat, the drawings of which appear with this paper.

The "Ice-yacht Challenge Pennant of America," the emblem of championship, and the blue ribbon of the ice, has played a most conspicuous part in quickly developing the best points in ice-yachts. Before the advent of the "Robert Scott," this pennant, which is open to competition by any organized ice-

yacht club of America, or, for that matter, of the world, was sailed for and won by the "Phantom" of the New Hamburg Club on March 5, 1881. On February 6, 1883, the next contest took place, the Poughkeepsie Club being the challengers. There were twelve yachts in this race, amongst them the "Robert Scott" under a changed name, and the "Jack Frost." The course was ten miles to windward and return, making twenty miles in all, and a time limit was fixed of one hour fifteen minutes or no race. Here the superiority of the "Scott" rig was quickly demonstrated, for this yacht easily won the race in 57 minutes, followed 4 seconds later by the "Jack Frost," which was a long way in the lead of the remainder of the contesting yachts. The Shrewsbury Club from New Jersey then challenged with their fastest yacht, the "Scud." This yacht was radically different, both in construction and rig, from either the older Hudson River or the "Scott" types. She was very rigidly constructed, her runner-plank was trussed, so that there was absolutely no give or spring to it, and her runners were long and without rocker, giving the yacht a strong hold of the ice; and her jib was large and set flying, also projecting considerably over the end of the bowsprit, to which it was attached by a toggle or swivel joint. There was an attempt at a race, which failed owing to lack of wind; but the "Scud" seemed fast in the light airs and soft condition of the ice, and she led the fleet when the yachts were stopped and it was seen that the race could not be made in the time required.

The next morning, February 23, 1883, the yachts were sent off, amongst them the "Haze," a celebrated old yacht, now modelled after the "Scott" and "Jack Frost." There were eight yachts in this race, including three of the new rig, four of the old, and the "Scud," different, as I have said, from them all. The conditions were fair, the ice good, and a fine, whole-sail breeze to send the yachts over the course, which was twenty-five miles instead of the usual twenty miles. "Jack Frost" won easily, with the "Haze" a good second, and next the "Scott" boat, with the "Scud" last of all. "Jack Frost" covered the distance in 1 h. 14 m. 35 s., and was 21 m. 36 s. ahead of the "Scud" at the finish.

The Shrewsbury men took their crushing defeat philosophically, and pluckily resolved to try again the following season,

which they did, constructing during the interval several new boats, one of which, the "Dreadnaught," was of the "Scott" type, only she had a rigid runner-plank. The Poughkeepsie Club had increased its fleet by another new yacht of the improved model, called the "Northern Light." This race for the Challenge Pennant of America was sailed February 9, 1884, and was not particularly important in results, except to emphasize and impress upon the Hudson River yachtsmen that they were developing their ice-yachts upon the right lines, and that, generally speaking, they possessed the fastest yachts in existence. The Shrewsbury Club entered four yachts, only one of which got a place. The race, over a twenty-mile course, was won by the "Haze" in 1 h. 05 m. 30 s., followed by the "Dreadnaught" a minute later, with "Jack Frost" close to the "Dreadnaught," and then the "Northern Light."

The New Hamburg Club having added a new yacht to its fleet, the "Zero," challenged the Poughkeepsie Club for the Pennant, and this race was sailed February 14, 1885. Fourteen yachts competed, seven from each club. The "Zero," owing to a foul, withdrew, but she could not have won. At the finish the time of the four leaders only was taken, and they were "Haze," "Jack Frost," "Northern Light," and the "Scott" boat, all of the Poughkeepsie Club, and all of the improved rig. The time of "Haze" was 1 h. 01 m. 15 s. for the twenty miles, with "Jack Frost" a few seconds behind. A claim of foul by the "Jack Frost" against the "Haze," and which seemed a valid one, not being allowed, many of the members withdrew from the Poughkeepsie Club and then formed what is the present Hudson River Club.

The Shrewsbury Club, still confident of their ability to win the coveted championship, had constructed two new boats, one a jib-and-mainsail, of which nothing need be said, and the other the "Scud," which was altered into a lateen rig. The reports which reached the Hudson said she was very fast. She had a large sail which was hoisted up between two short sheer poles or masts that joined at the top, spread apart, and were fastened to the runner-plank at their lower ends; the halyards supporting the sail and spars were rove through blocks attached just beneath the apex of the masts. The sail area was about 600 square feet, and this all being in one piece made a very hand-

some flat sail. Of course this rig meant heavy spars. "Scud's" boom or lower yard was over 52 feet long, and the upper one 36 feet. The runner-plank, as usual, was rigidly trussed from end to end. The race was sailed February 18, 1885, distance twenty miles. The Shrewsbury Club entered three yachts, and the Poughkeepsie Club the same. The "Northern Light," which had been improving steadily since the race of February 14, won easily, beating the second yacht, which was Shrewsbury's "Dreadnaught," 02 m. 43 s. The "Scud" was literally nowhere. The explanation given for this was want of wind, and yet the time made by the "Northern Light" was 1 h. 08 m. 42 s., which showed the race was a fast one, and in point of fact there was a strong breeze blowing during the race.

At the same time that the Shrewsbury Club built or altered the "Scud" into a lateen, the writer of this also conceived the idea of a lateen, and constructed a small boat of this description, with a sail area of about 200 square feet, and from the experience gained followed this small yacht by a larger one of about 600 square feet area; but, although at times there seemed a great deal of merit in this type of rig, the consensus of opinion was that it was not adapted to North River sailing, and that the jib-and-mainsail rig was not only faster, but much better balanced. Nevertheless, the Shrewsbury Club were not yet convinced that the lateen was not the faster type of yacht, and it was not until after several more defeats that they gave up and altered the "Scud" back to her old jib-and-mainsail rig.

The next contest for the Challenge Pennant took place February 14, 1887, the Hudson River Club challenging Poughkeepsie, as, it will be remembered, "Northern Light" won the last race. "Scud" having joined the Poughkeepsie Club was entitled to enter the race, and did so. The interest in this trial was keen, as several new yachts had been constructed, the famous old "Icicle" now appearing as a new yacht of approved modern type, spreading 735 square feet of canvas, "Reindeer" a jib-and-mainsail, and "Avalanche" a large lateen, built by an enthusiastic member of the Hudson River Club who had not yet lost faith in lateens. Thirteen yachts came to the line. "Jack Frost" won, closely followed by the "Northern Light," with the "Scud" in the tail-end

of the procession. The time of the winner was 43 m. 40 s., but the distance was over a sixteen-mile course in place of twenty.

During this race a lateen-rigged yacht from the Carthage Landing Club made its appearance, and though not in the race the speed of this yacht surprised all who witnessed it. Her name was "Eugene," and it was not long before she became the property of the Commodore of the Hudson River Club, and her name was altered to "Vixen." She is undeniably a fast yacht for her size, as she is small, being only 335 square feet sail area; and whilst it cannot be said that this yacht has ever won any important victories she serves to show possibly what might be accomplished in a larger yacht. The manner in which she differs from the other lateens is the method of supporting the sail, and which seems to give a better draught to it. This is done by a long wire-rope span connected at the outer end of the upper yard and leading thence over a groove on the top of the sheer poles to the lower end of the yard, where it is connected with the spar by a lanyard; the sail is hoisted in the usual manner, then a strain is placed on the whip, and the halyards relaxed so that the sail is suspended by the whip or span. Very simple it seems, and yet it really does make a better-fitting sail and consequently a faster boat.

The Carthage Club has constructed another lateen, called the "Ranger," upon the same lines as "Vixen," but larger. "Ranger" has met the yachts of the Hudson River Club but once, in the race for the Poughkeepsie Challenge Pennant, which is a local emblem of the championship of the Hudson River, when she did splendidly. This race was won by "Blitzen," a boat of moderate power, driven by 600 square feet of sail area. The "Ranger" was second, when she broke down near the finish; and had this mishap not occurred, it is possible she might have won, as she was but a few seconds behind "Blitzen."

Shrewsbury having again challenged the Hudson River Club, now the holder of the much-coveted Pennant, there was sailed a race on March 8, 1888, when "Icicle" came out victorious. Her time was 34 m. 50 s. for the distance sailed, which was only twelve miles owing to soft ice. It is doubtful if "Icicle" would have won had it not been for the capsizing

of "St. Nicholas" towards the latter part of the struggle and as she was turning the upper mark with a long lead.

This race seemed to have convinced the New Jersey men that the lateen was "not in it." On February 25, 1889, Shrewsbury again tried to win the Pennant. Fourteen yachts were entered in this very hotly contested race, and "Icicle" finally won by the narrow margin of one second over "Reindeer;" "Scud," now altered to jib-and-mainsail, doing better and coming in fourth boat. "Icicle's" time was 51 m. 41 s. for the sixteen miles sailed.

Owing to the poor condition of the ice and want of wind, another race for the Challenge Pennant of America was not sailed until February 5, 1892, the challengers being, as usual, the North Shrewsbury Club. It was a grand day for a test, there being a strong, steady wind blowing straight down the river. Only five yachts entered. "Icicle" led at the start, but was soon passed by "Blitzen." This yacht came to grief and withdrew, leaving "Icicle" a practical walk-over, so far ahead of the others was she. "Scud" finished last in a demoralized condition. The distance sailed was $14\frac{8}{10}$ miles, and "Icicle" covered it in 46 m. 19 s.

A few years ago "Jack Frost" ran away, and, pitching her owner out, she ran into a wall of rock on the river shore and was completely wrecked. So a new "Jack Frost" was built and an endeavor made to see how large a boat could be constructed. As designed this yacht was 52 feet long, 28 feet beam, and carried 1010 square feet of sail area; but it was quickly and pointedly ascertained that there was a limit in size beyond which it did not pay to go, and consequently she was cut down to her present size, 49 feet long, 28 feet beam, and a sail area of 720 square feet.

In 1884 the writer experimented with a cat-rigged yacht of 450 square feet sail area. This boat was tried once, and the result was so unsatisfactory that she was altered immediately into a jib-and-mainsail rig. The next cat-boat was built by the Commodore of the New Hamburg Club, and after many breakdowns I am informed she now holds together and sails well, but she is too small in size ever to compete successfully with the larger jib-and-mainsail-rigged yachts. Moreover, this question of cat-rig has, I think, been settled in the contest for the Challenge Pennant of America, which was

sailed this season. The Commodore of the Orange Lake Club has had great faith in a large cat-rig, and he built one certainly large enough to test this question thoroughly. She is very heavy, and very strongly put together, and has one enormous sail of over 800 square feet area, which is placed of necessity well forward to balance the boat. "Shadow" is her name.

The race occurred February 9th, and was one of great interest, not only on account of the entry of "Shadow," the large cat-boat just mentioned, but also to see what the new "Jack Frost" could do. The course was twenty miles. The Hudson River Club entered five yachts, "Icicle," "Dragon," "Northern Light," "Blitzen," and "Jack Frost," as against "Shadow," the representative of the Orange Lake Club. There was a steady, whole-sail breeze blowing from the south, and the ice was firm and hard.

A novel feature in starting was introduced for the first time. Heretofore, in all contests for the Pennant, yachts drew for positions, and were lined up accordingly to await the signal to go. This was a very unfair method, as one yacht was sure to draw the windward or best position; and as the line was a long one when a number of yachts started, it is equally true some other yacht must perforce draw the worst position, or, in other words, be placed at the start to leeward of the whole competing fleet. This in many instances amounted, as soon as the yachts were off, to a distance of a fourth of a mile, and as the yachts were simply timed in their order as they finished, without allowances or corrected time, it can be readily seen some boats were practically out of the race before they had started, by an unlucky chance in the number drawn. To obviate this inequality it was ordered that all yachts should start flying, over an imaginary line between the flag and the shore. A preparatory signal was given five minutes before the start; then a warning one exactly four minutes later, to show that only one minute was left; and then the starting flag, when yachts were at liberty to cross the line. This way of starting not only did away with blind luck, but allowed something to be gained by a skilful helmsman combined with accurate judgment of time in placing his yacht on the line as the starting signal was given, and to windward, if possible, of his rivals. It also

meant that competing boats would be nearer together and the result of the race much more satisfactory and conclusive.

The trial on February 9th of this new mode of sending the yachts off, considering no one had practised it before, was successful, and the start was a fairly even one, and much more exciting to the spectators. All the yachts crossed the line properly save "Icicle," whose helmsman, by unfortunately mistaking the line as the signal "be off" was hoisted, started ahead and to windward of the others. "Jack Frost," though, soon overhauled and passed "Icicle," and steadily increasing her lead won the race and the Pennant in the fastest time ever made over a twenty-mile course, 49 m. 30 s. "Blitzen," "Dragon," "Shadow," "Northern Light," finished in the order named, "Icicle" crossing the line ahead of "Blitzen" about the same distance that separated them at the start, but her time was not taken, as she went off improperly.

I have now brought these interesting struggles for the championship down to the present time, and the conclusions I draw from the results are, that the Hudson River type as exemplified by the leading jib-and-mainsail yachts belonging to the club of the same name, is the best adapted for racing or sailing for pleasure. The essential elements that all these yachts possess in common are: lightness, combining great strength of construction; a runner-plank that has considerable elasticity or spring to it, the effect of which is not only to make the boat more comfortable to the user, but I think also, in connection with the long runners, hung well back and rockered towards their forward ends, a great factor in attaining speed, as the impacts or blows resulting from inequalities of the ice are distributed easily and more slowly to the swiftly moving mass of the boat taken as a whole.

To explain what I mean: Take one of the large yachts; her weight would be at least 3000 pounds, including everything. Move this body, say, at the rate of forty miles an hour, or $58\frac{6}{10}$ feet per second; a hard, frozen hummock of snow or ice is encountered; now if the plank is rigidly trussed and the runners straight or without rocker, the blow must be a severe one, and the shock to the other parts of the yacht much more severe, entailing heavier construction in all its parts, hence increased friction and a loss in speed. Whilst, on the other hand, with

a properly proportioned flexible runner-plank, and an easy, gradual rocker to the runners, the yacht so equipped will glide up the obstruction, and shooting ahead clear of the ice, drop down with very little perceptible jar, though the runner-plank may have been deflected, as I have often witnessed, six or seven inches vertically from its normal arched position.

The angle or bevel of the runners is somewhat a matter of fancy, many of the fastest yachts having two sets of runners, the one with a sharp or acute V-shaped cutting edge for very hard ice, and the other pair of a more obtuse angle, just a trifle over 90°. The material used for runners is generally a hard cast-iron V-shaped shoe bolted to an upper part of well-seasoned oak. These are attached by a pin through a metal bushing in the runners to the chocks, which are in turn bolted securely and braced by knees to the runner-plank. The material used for these planks and also for the body of the yacht is either basswood or butternut. Ash is used for runner-planks when they are required to be very large or support considerable weight. The greatest care and attention are bestowed upon the sails, their quality, and the way they fit. Yachts of a few years ago spread very heavy canvas in comparison with the size of the sail. This has, I think, been found an error, and much lighter sails are now used. No doubt further improvement in this direction is desirable.

In the selection of material for a first-class yacht, great pains are taken to get only the very best growth of timber, which is usually picked out on the stump and taken to the nearest mill to be properly sawed out. The finest crucible-steel wire should be used for shrouds, stays, and fore and aft side guys. Turn-buckles should be hand-forged. As windage plays an important part in the speed of ice-yachts, care is taken to reduce it as much as possible, and to that end masts and spars are as short and light as is consistent with properly setting the sails and the requirements of safety. All wood-work has the highest cabinet finish. The cost of a yacht such as I have described, and about 48 feet long, complete in every respect, would be about $900.

Before closing it may be well to consider the wonderful and phenomenal speed attained by these interesting productions for winter sport and amusement.

Absolutely reliable data beyond the championship races

are few and far between, for it is seldom a course over which other races take place is accurately measured. The distances for the pennant contests are known by marks on the shore which have been placed there permanently by surveys, and in placing the buoys or turning-marks on the ice the greatest pains are taken to have them accurately established. In order to examine this matter of speed, I have made a table of the races for the Challenge Pennant, showing all the particulars, especially the distances between the marks, and therefore the lengths of the courses sailed, and I believe these distances to be substantially as stated. The course on February 5, 1892, was surveyed, and also measured by a registering wheel. I have also plotted on paper the approximate distances an ice-yacht would actually sail in covering the various courses. These results are tabulated on the sailing card. In working this out the river was laid off as half a mile wide, which is about the average width where the races take place, and as most of these were sailed with a wind blowing or drawing nearly straight up or down the course, which also is always up and down the river, the calculated distances sailed should not deviate to any great extent from the real distances. At any rate the plan adopted has seemed to the writer the best way of arriving at anything like the truth.

It will be seen by inspection of the table that the fastest time made in any of the races for the pennant was that of "Jack Frost," February 9, 1893. The twenty-mile course was sailed in 0 h. 49 m. 30 s., or at the rate of a mile in 02 m. 28 s. for that distance, but the calculated distance the yacht sailed was 31.38 miles, and this means a mile in 01 m. 34 s. The slowest rate occurred February 18, 1885, when it took "Northern Light" 1 h. 08 m. 42 s. to sail the twenty-mile course. This, it will be seen, is at the rate of a mile in 03 m. 26 s., but in reality 02 m. 11 s., as the calculated distance sailed was 31.36 miles.

The average rate of speed for these races is 01 m. 55 s. per calculated mile; and, as I believe a yacht in actual practice will sail over rather than under the calculated distances, it is safe to assume that the speed of an ice-yacht with a strong, steady breeze, over a true course to windward and return, is faster than this rate of a mile in 01 m. 55 s. The narrowness of the river forces the boat to tack or alter its course fre-

RACES FOR THE ICE-YACHT CHALLENGE PENNANT OF AMERICA.

Name of Winning Yacht.	Club.	Date.	Distance between Buoys in Miles.	Number of Times Sailed Over.	Total Length of Course in Miles.	Calculated Distance Sailed in Miles.	Time.	Apparent Rate per Mile.	Calculated Actual Rate per Mile.
							h. m. s.	m. s.	m. s.
PHANTOM....	New Hamburg *vs.* Poughkeepsie	March 5, 1881	....	....	20	....	0 57 14	02 51	
AVALANCHE OF ROBERT SCOTT............... ..	Poughkeepsie *vs.* New Hamburg	February 6, 1883	10	Once	20	31.38	0 57	02 51	01 49
JACK FROST.........	Poughkeepsie *vs.* North Shrewsbury	February 23, 1883	2½	Five	25	39.20	1 14 35	02 59	01 54
HAZE.......	Poughkeepsie *vs.* North Shrewsbury	February 9, 1884	6 66/100	Three	20	31.38	1 05 30	03 16	02 05
HAZE.........	Poughkeepsie *vs.* New Hamburg	February 14, 1885	2	Five	20	31.38	1 01 15	03 03	01 57
NORTHERN LIGHT..........	Poughkeepsie *vs.* North Shrewsbury	February 18, 1885	2½	Four	20	31.38	1 08 42	03 26	02 11
JACK FROST....	Hudson River *vs.* Poughkeepsie	February 14, 1887	2	Four	16	25.10	0 43 40	02 43	01 40
ICICLE......................	Hudson River *vs.* North Shrewsbury	March 8, 1888	2	Three	12	18.83	0 36 59	03 04	01 57
ICICLE..	Hudson River *vs.* North Shrewsbury	February 25, 1889	2	Four	16	25.10	0 51 41	03 13	02 03
ICICLE..	Hudson River *vs.* North Shrewsbury	February 5, 1892	1 44/100	Five	14 4/10	22.92	0 46 19	03 09	02 01
JACK FROST................	Hudson River *vs.* Orange Lake	February 9, 1893	2	Five	20	31.38	0 49 30	02 28	01 34

quently when sailing either to windward or off the wind, which not only increases the time, but also the distance over a given course. One point must always be borne in mind, and that is, that an ice-yacht invariably sails close-hauled, that is, with her sails trimmed flat in, whether in beating to windward or driving off before the wind. This is easy to comprehend when going to windward, for here a boat on ice sails the same as one in the water, but off the wind or sailing free it is another matter. It can be readily understood that in this case if sheets were started and sails were allowed to go off, so as to be at or nearly a right angle to the wind, the yacht would not advance to leeward quite as fast as the wind, as some force must be expended in overcoming friction; hence it is that in sailing before the wind the sails are trimmed close aboard, so that the course of the yacht to reach a given point to leeward the fastest would be 150° or 13⅓ points from the wind, when the advance to leeward would be one and a half times that of the wind itself.

The explanation of this curious feature of ice-boat sailing cannot better be described than in the paper Mr. N. G. Herreshoff, of Bristol, R. I., has so kindly written for me. Mr. Herreshoff's well-known ability as an engineer and his fondness for mathematical problems must lend great interest to it. It will be found at the end of this paper in his own words. Extraordinary rates of speed for short distances are constantly occurring, but, as I have stated before, they are not over surveyed courses. The writer, though, to test the question, laid off a measured mile on the ice, and when the conditions of wind were favorable, tried a number of small yachts over it. The best record was 59 s. Estimated speeds, that is, sailing up or down the river between known landmarks, have given still higher rates of velocity; in one instance a passage was made by two yachts where the time made was believed to be at the rate of eighty miles per hour. That this very great speed is probable or possible, is not to be doubted, but it occurs very seldom on the Hudson, as the danger of colliding with the rocky shores makes each helmsman keep his slippery charge under control.

I take pleasure in acknowledging my obligations to Mr. Irving Grinnell and Mr. John A. Roosevelt: to the former for plans of "Whiff" as a type of the older Hudson River yacht

before the advent of the "Scott," and to the latter gentleman for the many interesting photographs he has so kindly furnished.

MR. NATHL. G. HERRESHOFF'S EXPLANATION.

BRISTOL, R. I., Dec. 1892.

The resistance of the water to a sailing boat, although very small at a slow rate of speed, increases enormously as the speed increases, and entirely prohibits a very high speed in any sailing vessel. For she must have weight in order to give her sufficient stability to carry her sail, and considerable immersed surface properly placed, to prevent her from making leeway. The result is that the displacement of so much water by her great weight generates a series of deep waves, which absorb an enormous amount of power. And as the frictional resistance of a fluid increases as the square of the velocity, the amount of power absorbed in the surface friction also becomes large at high speeds. These absolutely check a very high rate of speed being obtained.

Under very different conditions the ice-boat glides along over the smooth, even surface of our frozen lakes and rivers.

The resistance of the runners in a good ice-boat is very small indeed. And, moreover, it does not increase sensibly with an increase of speed.

In making a rough estimate of the possible speed of an ice-boat, the resistance of the ice may be neglected altogether. And then the ice has only one office to perform, but a very important one—that of guiding the boat in the way it is desired to go. For this the runners have to be formed so that they will cut into the ice a very little, and the groove thus formed makes a wall of ice of sufficient obliquity to prevent the runners from going sideways by the pressure of the wind on the sail.

The wind resistance, or "windage," as ordinarily expressed, is then nearly the entire resistance the ice-boat has, and it prevents her from attaining an almost incredible speed. The windage of an ice-boat is a comparatively easy thing to deal with, since it is of the same nature as the driving power, and under the same conditions of boat and its sail will always be proportional to the driving power.

To explain the principle on which an ice-boat is moved by

the wind, we will first suppose she has no windage, and no resistance of any kind to progress in direction of the runners. The sail is set at an angle with the runners, so that the one side of the sail on which the wind presses and the opposite side of the runners form a wedge, one side of which is pressed on by the wind, and the other by the ice against the side of the runner, as shown in Fig. 1.

The side of the runner against the ice effectually prevents the boat from going sideways, but she is not prevented from going endways. The wind has no power on the sail other than in a direction perpendicular to the sail's surface; but this direction is not perpendicular to the direction of the runners, and it is easily seen has a tendency to press the boat ahead as well as sideways, and since the sides of the runners resist side motion, it goes in the direction in which there is no resistance.

Without going into the science of the resolution of forces and motions, I think it will be quite evident to any one that if the surfaces of our wedge have no friction to hold it in place, and if it is pressed on near its butt, it will move away from the pressure its full length, while the pressing medium is moving the thickness of its butt. And, moreover, if we suppose the butt of the wedge always cut off in direction of movement of the pressing medium, the distance across the butt in that direction will be the amount of movement of the pressing medium in the time the wedge is moving the length of its base, (see Fig. 2). And the larger the base of the wedge in proportion to the distance across the butt, the greater will be the velocity of motion of the wedge.

If we consider now the pressing medium to be a particle of air in motion, the direction of which is the direction of the butt of the wedge, and the rate of motion in a given time the breadth of the butt, the runners to be the base of the wedge and the sails the inclined surface of the wedge. Then will the length of the base of the wedge be the rate of motion of the ice-boat in the given time, and to any one on the ice-boat, the particle of air (if it could be seen) would seem to slide along the surface of the sail as the boat advanced, and to him has a motion in direction of the sail's surface, or of the inclined side of our wedge. This we will call the apparent direction of the wind. To the person on the ice-boat the par-

ticle of air will appear to move at quite a different rate from its real motion, and this motion (which we will call the apparent velocity of the wind) will be the length of the inclined surface of the wedge.

I think it will be easily seen that, if the angle of the sail with the runners is sufficiently small, the speed of the boat will be much greater than that of the wind, providing the direction of the wind is not too near parallel to the runners of the ice-boat. When the sail is set at an acute angle with the runners (as is always the case), and, as I have shown, the apparent direction of the wind is nearly that of the sail, its pressure on the hull and rigging of the boat—in fact on every part, excepting the sail itself—is an opposing force of more or less magnitude, increasing when the angle of the sail with the runners decreases. Actually the apparent direction of the wind is not the same angle with the runners as the sail is, but a little greater angle, and for a given angle of sail would always be greater by the same angle, whether the wind velocity be great or small, providing the ice resistance is so small as to be neglected.

Now, referring again to our wedge, if we substitute the apparent direction of the wind in place of the sail, on the inclined side, we have a triangle formed by the three sides of the wedge (see Fig. 3), in which we will suppose we know the angle, and which is the apparent direction of the wind with the runners of the boat, and the side W, which represents the velocity of the wind, and the direction of the side W, the direction of the wind. If the course of the boat is also supposed to be known, which is represented by the side B, we have sufficient data, by trigonometry, to determine the length of the sides B and A, which would represent the velocity of the boat, and also the apparent velocity of the wind.

By a simple geometrical construction the "Ice-Boat Problem" can be very easily solved, when the ice resistance is neglected, as shown in Fig. 4.

Draw the line AB, representing by its direction the direction of the wind, and by its length the velocity of the wind. From A draw AZ, making the angle BAZ equal to the apparent angle of the wind with the runners of the ice-boat. Draw Ab perpendicular to AZ. Draw mn perpendicular to AB,

bisecting AB. At the intersection of Ab and mn at o as a centre draw a circle cutting A and B. From A draw a line in the direction of the course desired for the ice-boat until it intersects the circle at X. Then AX will represent the velocity of the ice-boat on that course, and XB the apparent direction and velocity of the wind. The angle AXB is equal to the angle BAZ. For by construction the angle Aom is equal to BAZ, since AO is made perpendicular to AZ and om is made perpendicular to AB. Then AXB is equal to Aom, for the arc Am is half the arc AB. Am measures the angle Aom, and it also measures the angle AXB, which is proved in the theorem in geometry. "The inscribed angle in a circle has for its measure the half of the arc comprehended between its sides."

To know what course an ice-boat should go to attain the highest speed, draw AX, representing the course of boat, so that it will be a diameter to the circle, as Ab. Then bB will be the apparent direction of the wind, and it varies from the true direction by just a right angle, or 90°.

Draw a diameter to the circle which will be parallel to the direction of the wind, as cd. Then the course Ac will be that in which the boat should take to get to the windward the fastest, and the course Ad that in which she should take to get to leeward fastest.

It will be noticed that a boat can sail to leeward faster than the wind itself, the velocity directly to leeward being the velocity of the wind plus the velocity directly to windward, and that also the greatest obtainable velocity (on course Ab) is equal to the velocity to windward plus the velocity to leeward.

If the resistance of the ice were considered, it would complicate the problem somewhat. The angle α would be increased somewhat, and would become variable, depending on the pressure of the apparent wind, and in the diagram the curve which bounds the possible limit of velocity of the boat in different courses would not be a circle cutting B as well as A, but would only differ from the circle as drawn by a small amount in the parts that would be useful to refer to.

The probable angle α in a good ice-boat, and with ice in prime condition, is about 30°. Constructing the diagram upon this angle, $\alpha = 30°$, we have Fig. 5.

Thus it is shown that the closest the boat will go to the wind is 30° or 2⅔ points. That the best course, or the one that will take the boat farthest to windward, is 60° or 5⅓ points from the wind, when the advance to windward would be at the rate of half the velocity of the wind, while the actual velocity is equal to that of the wind. The boat encounters the greatest apparent velocity of the wind, when her course is 90° or 8 points from the wind, when the apparent wind is twice the actual velocity. The greatest speed of boat is attained when 120° or 10⅔ points from the wind, then her speed is twice that of the wind, and the apparent direction of wind is 90° or 8 points from its true direction. The most rapid progress to leeward would be made when sailing 150° or 13⅓ points from the wind, when the advance to leeward would be 1½ times that of the wind, and the apparent velocity of the wind would be equal to its true velocity.

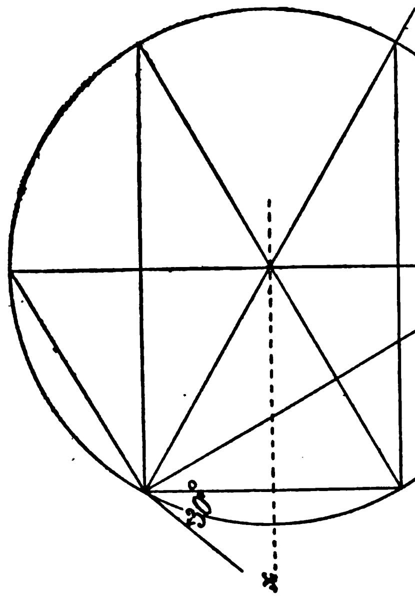


FIG. 5.

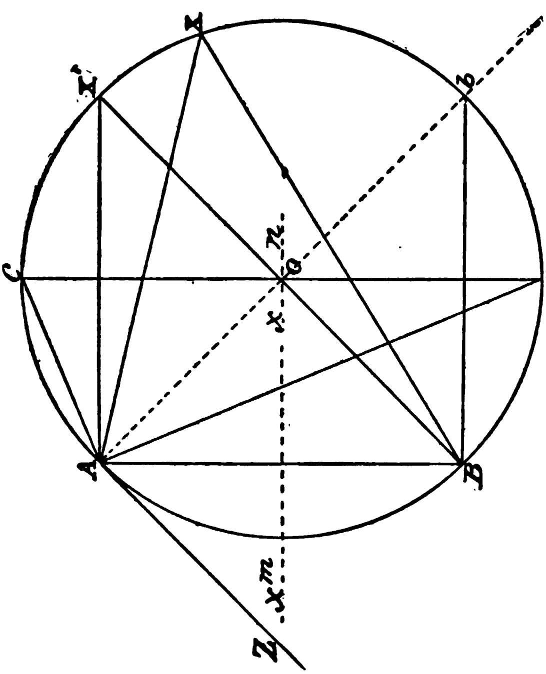


FIG. 4.

FIG. 3.

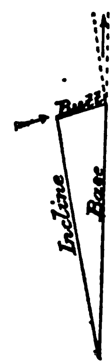


FIG. 2.

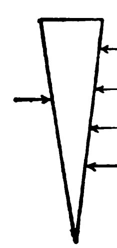
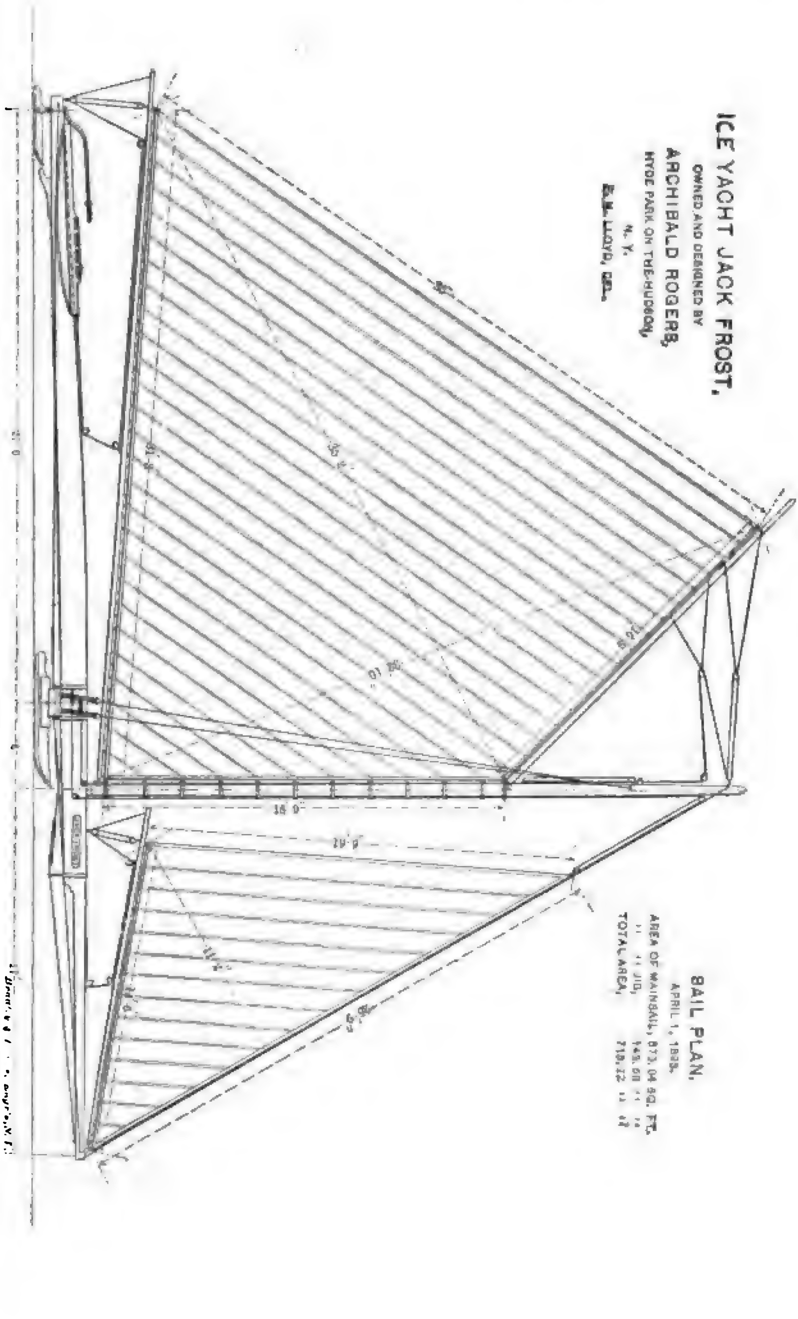


FIG. 1.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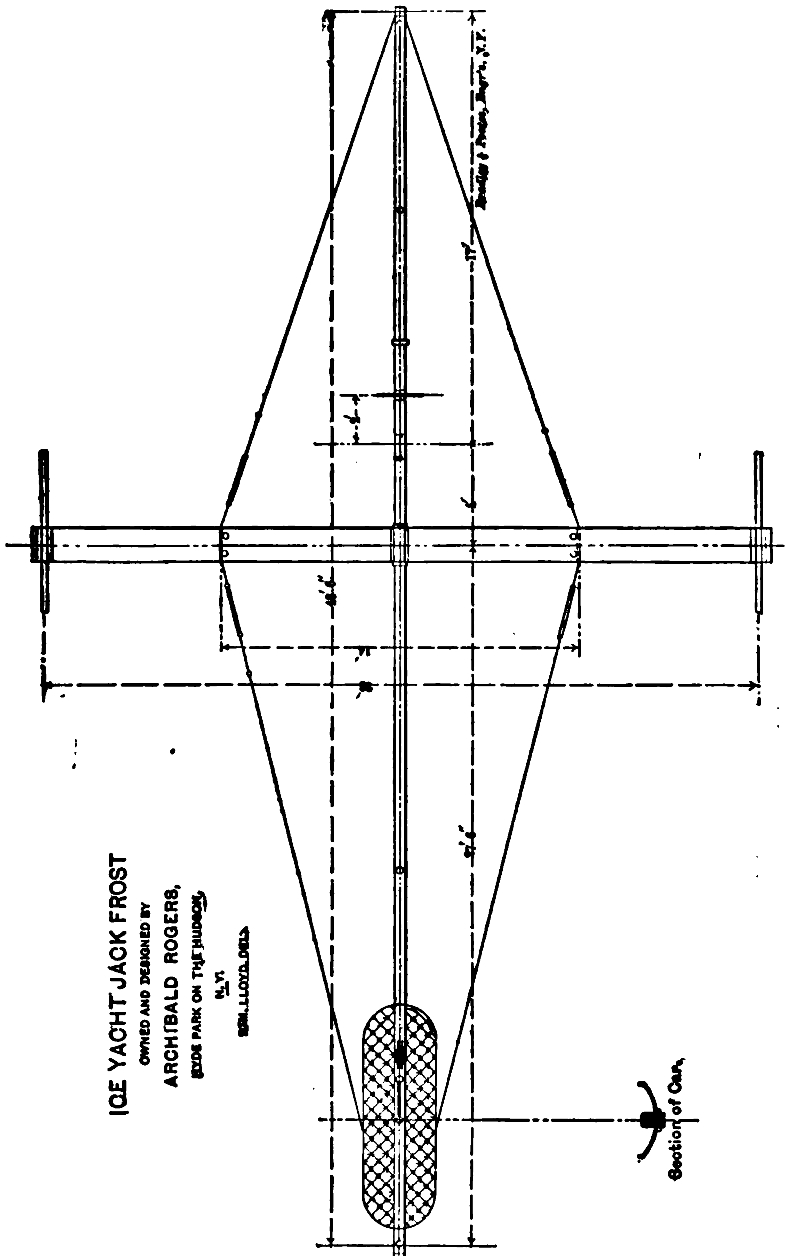
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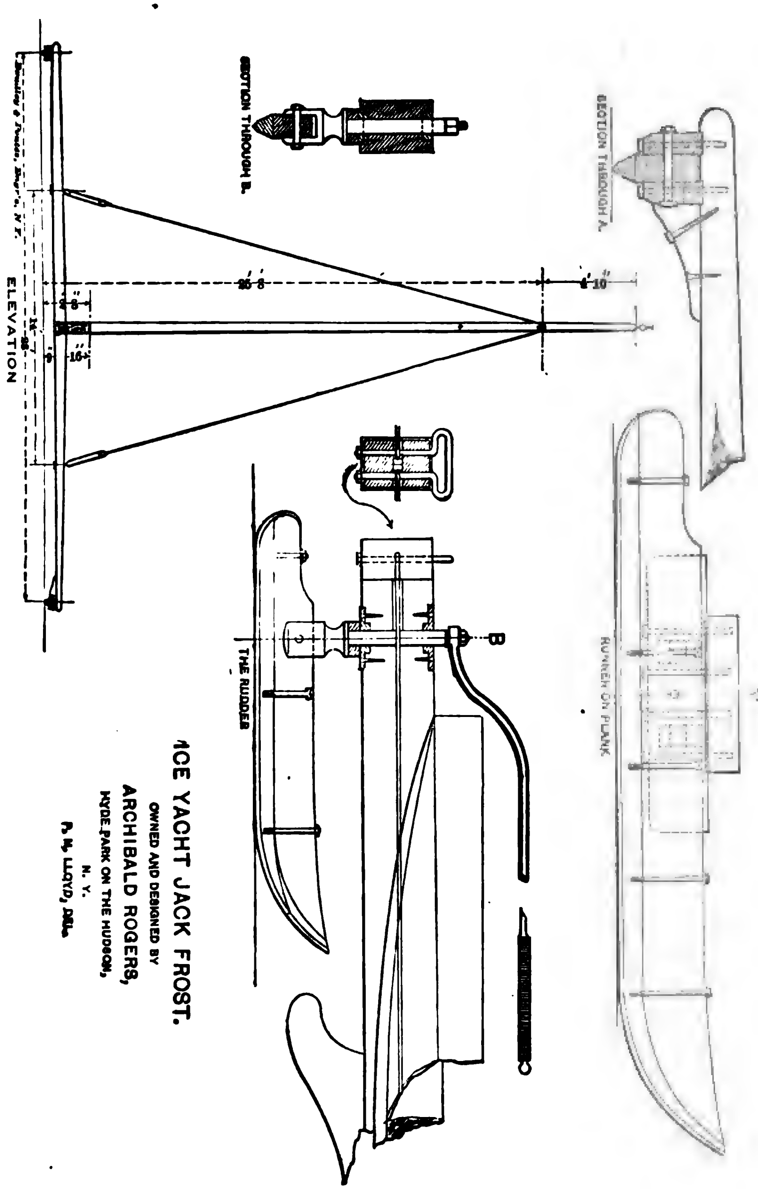

SECTION THROUGH B.
SECTION THROUGH A.
ELEVATION
THE RUDDER
RUNNER ON PLANK
ICE YACHT JACK FROST.
OWNED AND DESIGNED BY
ARCHIBALD ROGERS,
HYDE PARK ON THE HUDSON,
N. Y.

XXX.

STEAM-ENGINE BOILER-FEEDING.

By JAMES WEIR, Esq.,

Holm Foundry, Cathcart, Glasgow, Scotland.

1. Every steam-engine to perform or transmit work must receive steam at a greater pressure than that at which it exhausts.

2. The efficiency of every steam-engine depends—
   (*a*) On getting the full initial, or boiler, pressure on the piston; and
   (*b*) On returning the feed-water as near the exhaust temperature as possible.

3. Every cylinder of a compound engine is a simple engine.

In the treatment of a subject such as that which forms the material of this paper, it is open to the writer to adopt various methods, according to the different ends he may have in view, or the characteristics of the audience whose attention he desires to arrest.

Where research or discovery have brought new facts to light which form a denial or refutation of accepted ideas, these facts may yet be so treated as to appear in support of such ideas. Opposed to this method of judging experimental fact by the precedent opinion of authorities is that in which experiment is allowed to speak for itself, and to suggest a fresh line of thought, without being distorted to maintain the established, but not necessarily correct, views on the subject in hand.

The statements (1) and (2) heading this paper will doubtless obtain the assent of every engineer, whether graduated in the school of practical experience, or under the approved professors in the most up-to-date technical college. With reference to the statement of fact contained in (3), perhaps there may be some who have not yet accepted this; and if so, it is desired that they will follow the arguments brought forward on its behalf in the following pages before they decide to reject it.

Twenty-two years ago the writer publicly enunciated the view contained in statement (3), the principle of which is now at work in the following adaptations in most of the engines propelling the mail and passenger steamships of to-day:

(1) Heating the feed-water by the exhaust-steam of auxiliary engines.
(2) Heating the feed-water by the exhaust-steam taken from the high and intermediate pressure cylinders of engines with two, three, or four cylinders in succession.
(3) Leading the exhaust-steam from auxiliary engines to the receiver of the main engines.
(4) In evaporators for producing fresh water from sea water by using exhaust-steam taken from one of the H. P. cylinders, and using the generated steam in the low-pressure cylinder, or for heating the feed-water.

In examining the central principle involved in these adaptations, let us keep in mind statement 1, with which we began, viz., Every steam-engine, to perform useful work, must have steam supplied to it at a greater pressure than that at which it exhausts. The capacity for doing work on the piston depends on this difference of pressure, and, as this is always accompanied by a change in temperature, it follows that the exhaust is always less than the initial temperature. For example, take a simple surface-condensing engine, with boiler working at 20 lbs. pressure; the initial pressure will then be 35 lbs. absolute, and we will fix the exhaust at 4 lbs. The temperatures of the exhaust and initial will then be 153° and 259° Fahr., respectively. Now, the practical problem is to get the exhaust-steam returned to the boiler.

This may be done in two ways: first, by pumping it back, in which case no work will be available, as it will all be ab-

sorbed in returning the exhaust. The second way is to condense the steam, and return it to the boiler as feed-water. To get an explanation of this method we must go to the boiler end of the cycle, and ascertain the condition of our working material, viz., water. The water in the boiler is under the same conditions as to temperature and pressure as the steam, i.e., 35 lbs. pressure and 259° Fahr. The heat expenditure needed to change 1 lb. of water into steam is 932 heat-units, and this addition of heat energy does not change the temperature of the water or the steam, provided the engine takes it away as it is produced.

As this is a most important point, I will state it again in another way. The water and steam in the boiler are at the same temperature and pressure, and if we add more heat they will increase in temperature and pressure, except we use a quantity of steam in the engine corresponding to the heat added; or, in other words, this addition of 932 heat-units changes 1 lb. of water into steam, and as long as the engine takes this away there is no rise in temperature. The sole change in the water is that it leaves the boiler as steam, and in passing through the engine it transmits work to the piston, and in so doing, the pressure and temperature fall from 35 lbs. to 4 lbs., and from 259° to 153°, respectively. It is then exhausted as steam (minus transmitted work).

At the boiler end of the cycle we had the heat disappearing and changing the water into steam, for the purpose of supplying work to the engine. At the exhaust end we have steam which we wish to get back to the boiler. When our one pound of steam left the boiler it was 726 times the volume of the water from which it was produced, and now it is 5589 times the volume of the original water. The duty of the surface-condenser is to reduce the volume from 5589 to 1, and this is done by exactly the reverse process to that which took place at the boiler end of the cycle, that is, by changing the steam back into water.

In this process we must remove 1007 units which become apparent by the heating of the circulating water. If our condenser were properly designed the exhaust-steam would be condensed to feed-water at 153° and 4 lbs. pressure. To get this water into a fit condition to be converted into steam at the boiler-pressure we must increase its pressure and tem-

perature to that in the boiler. Now let us examine how this can be accomplished.

First, by putting it directly among the water in the boiler (the usual practice). The result of doing this is that we increase our expenditure from 932 units to 1038 units, or 11 per cent.

Second, by putting it directly into the steam space, where it will be heated by the steam. In this case the expenditure is exactly the same as in the first, 1038 units.

Third, we can lead our feed-pipes through the waste gases on their way to the chimney. By doing this you are using what is called an economizer, and by this means are able to get the required temperature, provided the general design of your boiler is bad enough. This is not a feed-heater in the strict sense, as the legitimate use of these gases is to heat the cold-air supply to the furnaces.

Fourth, there is the system of heating the feed by taking steam direct from the boiler. It is surprising that this system has received any encouragement whatever, and that its advocates can distinguish any physical difference between heating the feed by steam brought from the boiler and by steam in the boiler. But where commercial advantages are to be reaped, no device, however absurd, will lack specious advocates.

In the foregoing examples, we have taken for granted that the surface-condenser was properly designed, and only performed its legitimate function, that is, to condense the exhaust-steam to water. The condensers, however, now universally used do more than this: they also act as refrigerators, by cooling the condensed water. They are good or bad according as they cool the water less or more. One point only need be mentioned in this connection, and this is a most vital one, which is common to all condensers, good or bad. The air-pump is employed to do double duty, i. e., to remove both the air and water, and it is a physical impossibility for an air-pump to draw air through its suction-valves if the water in the pump be at the boiling temperature, which would be the case if the water were at the temperature of the exhaust-steam.

The amount of air any pump will remove depends on the relative temperature of the pump: the colder it is, the more efficient. Therefore, to expend the minimum amount

of work in removing the air from the condenser, the air must be taken from the coldest part, and this is where the air will accumulate; in fact, it is the only part where the air can accumulate. The surface-condenser on the engine which we are considering is of the universal type and of quite the average efficiency, and delivers the feed-water at 103°, being 50° below the temperature of the exhaust. Through this defect in our condenser the expenditure for 1 lb. of steam will be raised 50 units, which can be saved by using a feed-heater working with exhaust-steam. This is feed-heating system I.

We will now disconnect the air-pump and see what opportunities are left for feed-heating when our engine is exhausting at the atmospheric pressure. We will retain the same boiler-pressure as in the previous case, and our engine will now work through a range of 20 lbs., from 35 to 15 lbs. The corresponding temperatures will be 259° and 212°. Our minimum expenditure will amount to 979 heat-units, 932 in evaporating and 47 in heating the feed-water. We will now use our condenser to reduce the exhaust-steam to water, and in this case there is no difficulty in getting the water at the exhaust temperature, and consequently no need for feed-heating. In the next case, instead of condensing our exhaust-steam we will lead it direct to the atmosphere, and take our feed supply from some other source, at a temperature of 50°. In this case our actual expenditure will be increased 162 units, from 979 to 1141 units, and we have now a great opportunity for feed-heating, which has been done by every rational engineer from James Watt downwards. The simplest and most efficient form of this feed-heater is to pass the cold water into the exhaust-steam and draw the feed supply from the exhaust chamber or feed-heater. This is feed-heater No. II, but it is identical in principle and is carried out in exactly the same way as in No. I.

The opportunity and possibility of feed-heating in a simple engine being thus limited to the temperature of the exhaust, attempts have been made in some few cases to carry this principle further. I will state briefly how this is accomplished, and show drawings of the general arrangements.

First, when the steam is carried very far on the stroke, there is very little expansion of steam in the cylinder, and consequently when the exhaust-port opens the pressure in the

cylinder may be much greater than that in the condenser. To take advantage of this for feed-heating, a subsidiary exhaust-valve, or an extra passage in the slide-valve, is made, and a portion of this high-pressure exhaust-steam is led through a non-return valve to a chamber through which the feed-water is passed on its way to the boiler. By this means it is heated more or less, according to the ratio of expansion in the cylinder.

The second manner in which the feed-water is heated above the main exhaust temperature is accomplished by cutting ports in the middle of the cylinder side, and fitting a non-return valve with pipe connections to the feed-heating chamber. By this system the feed is heated to a much greater extent than in the previous case, and the expenditure advantageously reduced.

The principle by which economy is effected in this case is more easily grasped and understood when treating feed-heaters in the compound engine, as they are both identical in principle and effect. In our analysis of the simple steam-engine working under various conditions of pressure, we have failed to discover any means whereby the feed-water can advantageously be heated above the exhaust temperature; we are therefore forced to admit, *that the minimum expenditure in every simple engine is the total heat necessary to produce steam at the boiler-pressure from water at the exhaust temperature.*

In the first two cases, we have used steam at 35 lbs. pressure and worked it in the first case down to 4 lbs., and in the other to 15 lbs. We will now take the same pressure and work it in two separate stages, i.e., as a compound system. In the first or H.P. cylinder we will work it between 35 and 13 lbs., and in the second or L.P. cylinder between 13 and 4 lbs. We have now two simple engines: the H.P., working between 259° and 206°, or a range of 53°; and the L.P. between 206° and 153°, or 53° range. The problem with which we are now confronted is: How can the expenditure in this compound system be reduced to a minimum? i.e. the minimum expenditure in a compound engine. Those who understand and accept as a fact "that every cylinder of a compound engine is a simple engine," will solve the problem by stating that each engine of the series ought to be treated as a simple engine, and the feed returned at the temperature of the exhaust.

The method of doing this is identical with that of the examples already given of the simple engines, viz., first by heating the feed to the temperature of the L.P. exhaust, then heating it by the H.P. exhaust. The expenditure will then be reduced to 985 units instead of 1038, as in the simple engine working through exactly the same range of pressure.

A survey of American works on the steam-engine has failed to find any reference to this important question, and even British technical writers have left the question untouched. Professor Cotterill, who had in his possession a full explanation and diagrams supplied by the writer a considerable time before the appearance of the latest edition of his work on "The Steam Engine," has, however, treated the subject very fully, but only correctly in so far as he has made use of the material supplied to him.

In thus attempting to deal briefly with the question of boiler-feeding, we have been led also to consider the rationale of feed-heating, and we may now summarize the conclusions we have been led to, as follows:

(1) The minimum expenditure of every simple engine is the amount of heat needed to raise the water at the exhaust temperature to steam at the boiler pressure.

(2) No legitimate system has yet been discovered for reducing this expenditure in the simple engine—feed-heating being only admissible through some defective arrangement.

(3) Feed-heaters are necessary in compound engines in order that the feed may be returned at the exhaust temperature.

Let us now give our attention to and examine *the effects of feed-water on steam-engine boilers.* The practical experience of the writer has been gained in connection with marine boilers of the return-tube type supplying steam to compound, triple, and quadruple engines at pressures varying from 80 to 180 lbs., and his experimental investigations have also been conducted on these. The deductions drawn in the following pages, though strictly referring to this class of boiler only, may, however, in the majority of cases, be taken to have a general application.

The first point we shall deal with is that of unequal expansion, regarding the cause of which many views are

prevalent. We shall confine ourselves to an examination of two, viz.: (1) Unequal expansion attributed to the main feed-water. (2) Unequal expansion attributed to the donkey feed-water.

With reference to the first, there are still current many extraordinary notions and theories regarding the behavior of the feed-water when put in the boiler. Many engineers believe that the main feed-water, being comparatively cold, —say from 160° F. to 280° F. below the temperature of the water in the boiler,—on entering the boiler takes a downward course at once, and thereby causes contraction of the plates in the lower part of the boiler, and consequent leakage from the joints. It is to be observed that the feed-water we are now working with is the main supply from the hot-well of a surface-condensing engine. We have to keep before us the fact that *when the main feed is being supplied to the boiler the main engines are working*, and that when the main feed is going in *the boiler is also working.*

Now, let us look at the condition of the water in the boiler when it is being evaporated. Efficient means have been taken to ascertain that there is rapid and complete circulation of the water in every part of both single and double ended boilers, and in no instance could the cold feed-water be detected in any part. Those who doubt this statement may verify it for themselves by the use of thermometers. The main feed-supply being just equal to the steam-supply and the rapidity of the circulation depending on this, it follows that an increase in the feed is an increased circulation.

Second. Unequal expansion due to the auxiliary donkey-feed. In considering this we have first to recollect that, *when the auxiliary or donkey-feed is used, the engines are usually stopped;* also, that *when the donkey-feed is going in, the boilers are at rest.*

The inevitable result of adding cold water to hot is that the cold water sinks to the bottom of the vessel. This is exactly what takes place in a boiler, as experiment has proved.

Now, the question is, How can this be prevented in the simplest and most efficient way? Certainly not by the feed-heater, which we have already characterized, taking direct steam from the boiler to the feed-heater, and passing the donkey-feed through it. It can be efficiently done by simply

passing the feed-water into the boiler in such a way that it gets heated before it reaches the bottom. There are various means of doing this, but only two need be mentioned. First. By leading the internal pipes through the boiler near the water-level and distributing the feed through the small holes in the pipe. Second. By leading the internal pipe into the steam-space, and delivering the water amongst the steam. By this means the feed will be instantly heated, if provision is made for the escape of the dissolved air. If this is not done, and the air allowed to accumulate, the water will reach the bottom comparatively cool.

Much damage is also done to boilers by unequal expansion not directly due to boiler-feeding; yet by a modification of the feeding arrangement this also can be remedied. This damage is brought about when raising steam by the water below the level of the fire remaining cold at any pressure, and only becoming heated when sufficient circulation is set up by the withdrawal of steam when the engines are started.

In some boilers it has been found to remain cold until the engines are working a little over half-speed, but in most cases the easing of the safety-valve for a few seconds will suffice to set up sufficient circulation. The damage, however, may be done before there is sufficient steam either to start the engines or to blow off at the safety-valve.

For the purpose of inducing circulation when raising steam, the apparatus known as the Hydrokineter, to which steam is led from an auxiliary boiler, is very extensively used. To promote circulation and prevent the water at the bottom cooling while lying under steam, the donkey-pump is arranged to keep up the circulation, and a simple and effective means of accomplishing this is by using a combination-feed check-valve. This arrangement is used when raising steam, lying under steam, blowing off, and pumping out the boiler when in port.

The next important point in connection with the feed-water is the question of corrosion, to the study of which the writer was led over twenty years ago on the introduction of the feed-heaters using exhaust-steam taken from the receivers of compound engines. In the course of a long series of experiments conducted by his firm, it was observed that no trace of corro-

sion could be found in the parts of the feed-heater exposed to the hot water. It was also clearly proved that, after this water had passed through the feed-pumps, it became very corrosive, the cause of this change being that to prevent damage to the pumps air was admitted. When the air-supply was shut off we had an example of the phenomenon known as the "water-hammer." At this time many plans were tried to overcome this difficulty, but they were all failures.

The attempt to pump the water without air was then given up, and we tried to heat the water in the boiler in the steam-space, in order to liberate the dissolved air. This apparatus, devised for the purpose, was called a Conserver, and was in every essential part the same as the feed-heater, but placed in the steam-space, and had a pipe led through the boiler shell, and fitted with a small pet cock, for removing the liberated air. The gases drawn off in this way were analyzed, and found to consist usually of oxygen, nitrogen, and traces of carbonic acid. When salt water from the sea was used the carbonic acid was 10 per cent of the whole, while in addition to oxygen and nitrogen there were some gases which had an offensive odor. About 500 boilers were fitted with conservers.

Before leaving this point, a few points peculiar to heating feed-water with the steam in the boiler may be stated. The feed-supply must be carefully regulated: if allowed to go intermittently, it leads to priming, and regulating the feed becomes troublesome with a large number of boilers. By closing the outlet for the gases, there is no chance of priming, as the feed-water falls through the accumulated air, which acts as a jacket and effectually prevents the water getting heated. From this cause the conserver proved an unsatisfactory arrangement and of little practical benefit, consequently its use has been discontinued for a number of years. It was conclusively proved by the use of conservers that neither gain nor loss resulted from heating the feed by direct steam.

The fact which specially came into prominence during the experiments spoken of has been already pointed out, i.e., that water was not the agent which oxidized the iron, but the gases dissolved in it.

We shall next examine how this action takes place, and the description will, it is hoped, be rendered more interesting by drawings of the apparatus employed, and by showing you

one of the most complete and useful forms of corrosion detectors.

From physical researches, principally by Bunsen, the following general statement is applicable to feed-water; the gases present, with the percentage of solubility in water at 32° Fahr., are: oxygen 4%, nitrogen 2%, carbonic acid 180%.

1st. At 32° Fahr. the maximum amount of gas is dissolved, and as the amount dissolved depends on the temperature, there is no gas dissolved at the boiling-point.

2d. The weight of gas dissolved is proportional to the pressure.

Note.—Hydrogen gas is also present in feed-water when zinc is used in the boilers, and, although it follows these laws in a general sense, its behavior is exceptional.

The writer's investigations proved that when these gases are dissolved in water they are in the true liquid state, and behave in every way as liquids.

3d. Gases dissolved in water will and do remain in the liquid state under any condition of temperature and pressure, except in contact with a gas, when they then immediately resume their state of equilibrium.

4th. Oxygen and nitrogen have no action on iron, when in the gaseous state, or liquid in water.

Note.—Granting the term "nascent state" to a dissolved gas at the instant when it is passing from the liquid to the gaseous state, then—

5th. In the nascent state oxygen combines directly with iron, forming hard iron oxide, which adheres to the iron surface and protects it from further action.

6th. Carbonic acid dissolved in water combines with iron oxide, forming iron carbonate, which is soluble in water.

It is a well-known fact that ferrous carbonate is instantly reduced to iron oxide by oxygen dissolved in water, and carbonic acid liberated.

With the above facts in mind, we may now trace the course of boiler corrosion as follows:

1st. When the feed-water contains only the constituents of atmospheric air (oxygen and nitrogen), a coating of iron oxide is formed, and if this is allowed to remain there will be no further action.

2d. When the feed contains, in addition, carbonic acid in

solution, the oxygen combines with the iron to form iron oxide, which is acted upon by the carbonic acid and changed into ferrous carbonate. This is dissolved in the water and reduced by the oxygen in it to iron oxide, while the carbonic acid is liberated and is free to attack more iron oxide, and so on. All that is thus necessary to keep up the corrosion is a supply of oxygen in the feed-water, as the amount of the carbonic acid remains constant.

Before finally leaving this subject, two practical examples may be given of forms of corrosion familiar to all marine engineers. Bearing in mind that the nascent state is effected by diminishing the pressure and raising the temperature of the water, let us, first, put an iron tube in a surface-condenser. Corrosion will only take place on the side exposed to the sea-water, and a few days will be sufficient to make holes through it. We have here present in the sea-water carbonic acid and oxygen, put into the nascent state by the heat transmitted through the metal to the water. Second, in the case of iron and steel screw-propellers we have the pressure increased on the face of the blade and diminished on the back, with the invariable result of corrosion only on the side where the nascent state is brought about by diminished pressure. The peculiar form that corrosion takes on a propeller is due to the painting. The paint covers or encloses little air-bubbles between the metal surface and the paint. When the pressure is removed from the paint the little air-bubble expands, bursts its prison-wall and escapes, allowing the sea-water to enter with its oxygen pick and carbonic-acid shovel to dig out these extraordinary cavities, with which we are all so well acquainted.

We may now summarize the conclusions to which we have been led, when considering boiler-feeding in relation to corrosion and unequal expansion, as follows :

I. To have effective circulation when raising steam we are compelled to use mechanical means from an independent source.

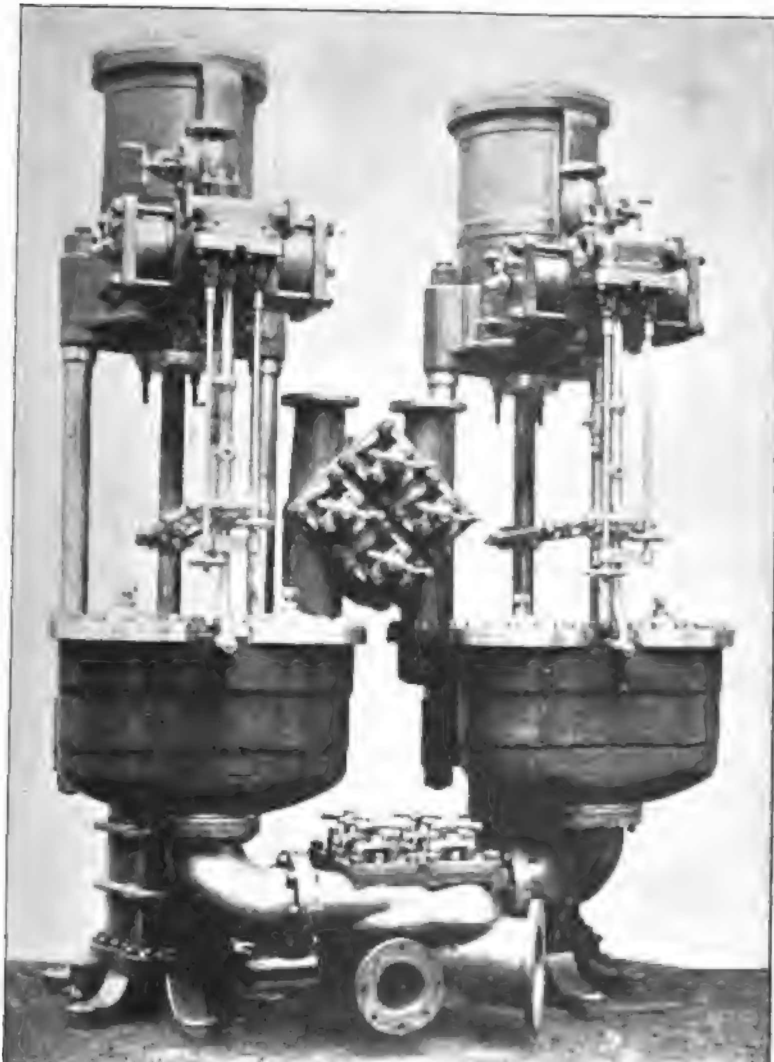
II. When the boiler is under steam, nothing is required if the feed is supplied in a rational manner.

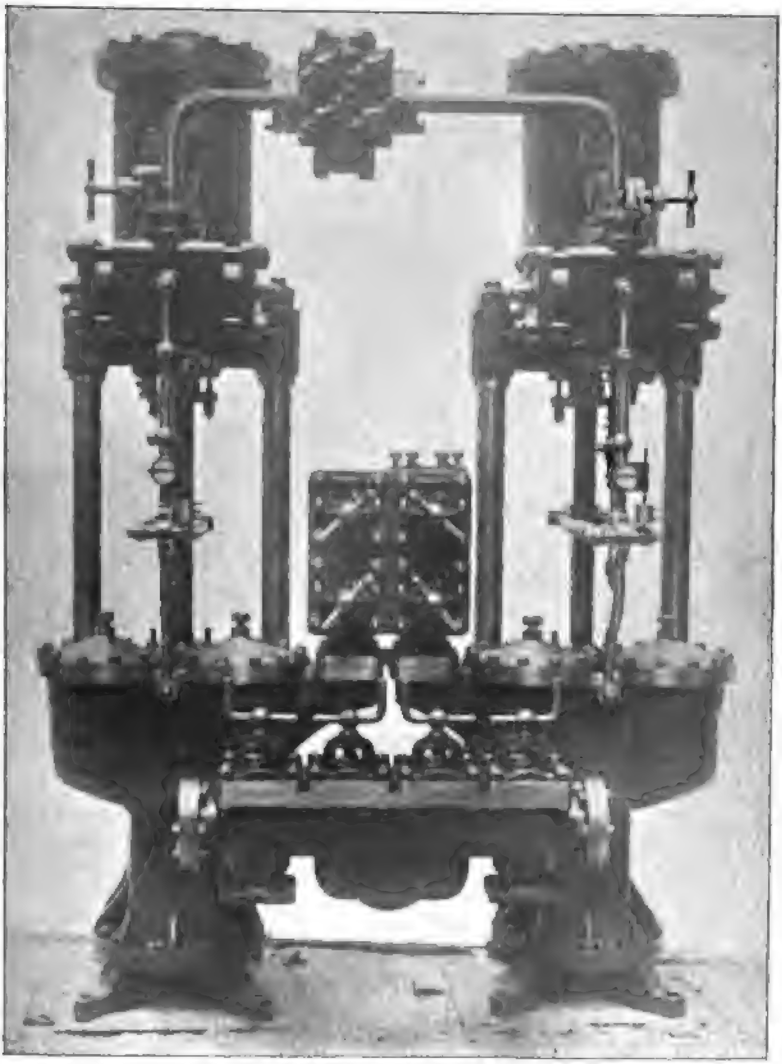
III. When the feed is at the exhaust temperature it cannot oxidize the boiler.

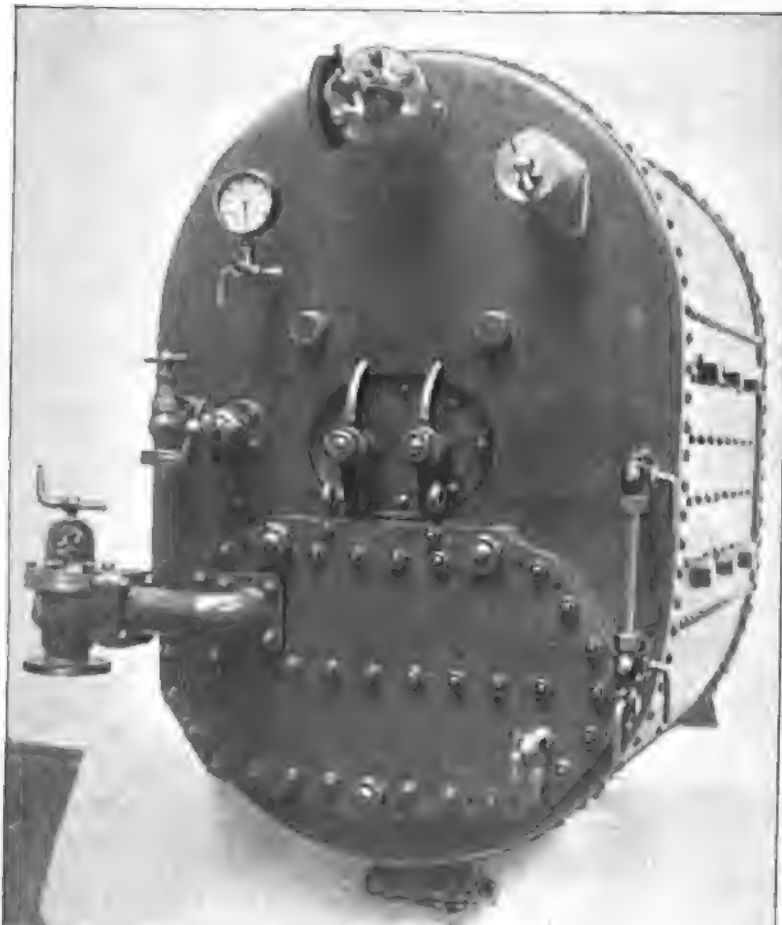
IV. Feed-pumps worked by the main engines add gases to the feed-water and render it corrosive.

There only remains for our consideration, how we can supply the feed at the exhaust temperature to the boiler without rendering it corrosive, the answer to which has already been indicated by the course of argument in the previous pages, viz., by using auxiliary donkey-pumps, fitted with control gear to prevent them drawing air. These are now in use in nearly all first-class, high-powered steamships, and the drawings of the following installations show various arrangements of this class of boiler-feeding gear. Besides illustrating the various points noted during this short survey, these drawings will, it is hoped, show how the various questions connected with boiler feeding have been successfully met in a wide range of the most recent marine practice.

NOTE.—The drawings referred to will be shown by lantern-slides at the Congress.







XXXI.

SPEED PREDICTION AND PROGRESSIVE TRIALS.

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I INTENDED to give a complete sketch of all the methods used in the prediction of speeds, but on investigation I found the subject so large and my time so limited, that I have thought it better to confine myself to a description of the more usual methods used by my firm.

When steam-power was first introduced on board ship, and for many years afterwards, more or less guesswork was the only method used, and the results were often disappointing. At first, also, on the introduction of the screw-propeller, the subject was so much obscured by fallacious ideas as to efficiency of the screw, that rules for determining speed were scarcely looked for. I am afraid that even now loose ideas exist upon this subject, notwithstanding Mr. Froude's admirable investigations; and it is a curious fact that ministers of the various religious bodies are most frequently attacked by this idea of the perfect screw, the efficiency each predicts for his particular screw varying from 100 to 200 per cent.

One of the first methods of predicting speed was based on the old Admiralty constant, commonly known as the $D^{\frac{2}{3}}$ coefficient. This formula has survived many attacks, and is of great service when rationally applied. At the same time it must not be forgotten that although called a constant it is in no sense constant.

When first introduced speeds were low, and surface friction was the principal element in resistance, and as $D^{\frac{2}{3}}$ is simply a rough way of expressing surface, the constant was easily

applied, and more or less accurate. It is still applicable, although in many cases wave-resistance is now the principal item; but it must be used with care for ships not very dissimilar, and the question of varying dimensions should be provided for in the usual way.

Whatever formula or method is to be used, the first essential is to have proper data to work from.

In the early years of steam-shipping the owners and builders were generally satisfied with only the top speed, and even this one speed was very often rendered unreliable, owing to unintentional errors or intentional cooking to make the speed appear greater than it really was.

The first experiments on speed and resistance of ships were carried out by the late Mr. Froude in the year 1867; and, as is well known, Mr. Froude formed one of the British Association Committee for the investigation of speed and power. The reading of the report of this committee so impressed my late brother, Mr. Wm. Denny, with the scarcity of information on the subject, and the value to be attached to model experiments, that, foreseeing the probable utility of experiments with full-sized ships at different speeds, he inaugurated the system now well known as progressive speed-trials. He communicated the results of his experiments up to that date in a paper read before the British Association in the year 1875.

Mr. Froude recognized the value of the results thus obtained, and there was a close intimacy between Mr. Froude and my brother which was fruitful of the very best results.

It has been the invariable custom of my firm ever since to progressively try all the vessels built by us, and the number of vessels so tried now amounts to 136.

I communicated, in a private letter to Assistant Engineer H. P. Norton of the U. S. Navy, a discussion upon a paper read before the Society of Naval Engineers in the year 1890, dealing with the question of speed-trials of fast ships. In that letter, which although not originally intended for publication was ultimately published by the Society, I gave a full description of how these progressive speed trials should be carried out. Perhaps it will be allowable for me to redescribe the method, as the present paper is intended to be more or less comprehensive.

The vessel about to be tried, before being placed upon the measured mile, should be run for a sufficient time so as to be quite certain that the fires are all in order, and that the maximum power which the engines and boilers can develop is being produced. The vessel should then be placed upon a proper measured mile, and two double runs with and against the tide should be taken in close succession. It is advisable to have the vessel on a straight course at least half a mile, and preferably a mile, before entering upon the measured mile, and preparation should be made for taking engine diagrams and observing accurately the time taken to run the mile by a well-trained staff of observers. Carefully rated chronographs only should be used for taking the times, and it is also desirable to test the indicators under steam, as the springs are liable to error.

Our general practice is to have at least four, and preferably six, observers for time—say two in the engine-room and four on deck. Each observer on deck independently observes the time taken on the measured mile. One observer is charged with the duty of signalling to the engine-room, which is done by means of the engine-room telegraph in the following manner: Thirty seconds or thereby before entering the measured mile the telegraph is put to "Stand By," and as soon as the mile-posts are in line the observer puts the telegraph to "Full Speed." This does not mean that the stop-valve or valve-gear is interfered with, but simply advises the observers in the engine-room that the steamer has entered upon the mile, so that the counter may be noted, and indicator-diagrams taken. At least two, if not three, sets of diagrams are taken from each cylinder while the vessel is on the mile.

About thirty seconds before the end of the mile the observer on deck again rings "Stand By," and when the posts come in line "Full Speed." Runs are made both with and against the tide, and for the highest spots we generally take two double runs.

The revolutions are then reduced by linking up so as to reduce the speed by half a knot or a knot, and another set of runs is taken, except that only a pair of runs is taken for each of the lower speeds.

As it is important to well define the upper part of the

curve, the spots should be taken at, say, half a knot interval for the first three higher spots, and thereafter at the lower part of the curve the speeds may be reduced by two or three knots, as found most convenient.

In every case the stop-valve and links should not be touched or altered during a pair of runs, even between the up and down runs when the vessel is turning at the end of the mile. It has been suggested that a single knot is too short a distance for fast vessels. Personally I do not think so, while I would have no objections to running two knots. I think, however, that in the other direction, when running the slow speeds, the distance might well be reduced to $\frac{1}{2}$ or even $\frac{1}{4}$ of a knot, and at the Gareloch mile, which is principally used for trials of small vessels, there is such a subdivided measured knot which we have found very convenient.

In regard to the accuracy of this method the first essential is to have a suitable measured knot. On the Clyde we are particularly fortunate at Skelmorlie. The course is sheltered, and the water is deep—about 40 fathoms. The depth of water should not be less than from 10 to 15 times the draught of the vessel, if less than this the speed of the vessel will be seriously interfered with. The Admiralty knot at Stokes Bay is almost totally useless from this cause, and I would refer those interested to remarks made by Dr. W. H. White, Chief Constructor of the British Admiralty, in last year's Transactions of the Institution of Naval Architects.

Given a good mile, the following are the errors which may occur: First, errors due to chronographs not starting and stopping promptly, and personal error of the observer. The sum of both these errors has never, in our experience, been more, as a maximum, than one second for a mile; this at a speed of 21 knots is important, but I have given the maximum. As a general rule several of the observers will have identical times, and I firmly believe that the error in taking the average is quite negligible.

The second error is due to the steersman: he may steer a serpentine course, which is bad not only from the fact that the course is lengthened, but also from the power absorbed by the rudder. This, however, is an error which is easily detected, and can be got over by having a carefully trained steersman.

The measured knot, marked with two posts on shore at each end, cannot by any method of running it be made shorter, but it can be made longer. We know that occasionally in making trials we are not quite square to the course; the error in no case exceeds two or three degrees, and the difference of speed resulting from this is quite negligible.

At the Skelmorlie mile tide is of little moment at the worst, and if the runs are taken, as they should be, promptly after one another, this effect may be neglected.

The only other influence is wind; speed trials should not be carried out when the wind is high, as this error cannot be allowed for. For ordinary steamers not having great deck erections the effect is small, unless a wind greater than a moderate breeze is blowing.

Progressive trials are very tedious, especially at the lower speeds, and several methods have been introduced for saving time. Notably, Professor Biles introduced a modification of what is known by sailors as the "Dutchman's Log." A piece of wood or other object is thrown over the bow, an observer is stationed at each end of the vessel at a known distance; then, by means of electric contacts, and a time clock actuating pens on a recording cylinder, the time taken in passing the chip is found, and the speed through the water is got therefrom. We carefully studied and tried this method, but we found it very unreliable, due to wind effects, wave effects, and the disturbance caused by the vessel passing through the water. I give in a small table results taken on the measured mile to show that this is the fact.

Biles Machine.	Measured Mile.
8.62	7.71
7.66	7.61
6.84	6.24
9.26	9.18
7.79	8.65

We pin our faith to measured-mile trials as the best method of obtaining the real speed of vessels; but this method of trial must not be confounded with long-distance trials, which is a test of the endurance of the engines and boilers.

On the Clyde we are again specially favored in having a known long distance to run on. The distance from the

Cloch to the Cumbrae Light is $13\frac{3}{8}$ knots. The course is more or less sheltered all the way, and if care is taken to commence the trials at about half ebb, or half flood, with a fast vessel a double run can be made without sensible error under favorable circumstances; but in so far as the tides are not constant, and the wind effect on this course is greater, we have generally found the speeds did not correspond with the measured-mile speeds, although in several instances they did so very closely.

We have occasionally found on the Cloch and Cumbrae that we got a better speed against the supposed tide than with it, when developing the same power, and the engines running at practically the same revolutions; this must be due to wind effect and tide eddies.

Another method of taking the speed which is common in the British Admiralty is by means of a log. I do not deny the possibility of getting a fairly accurate result by this method with a carefully rated log, but the conditions of wake interference caused by the vessel passing through the water and by the propeller are so complicated, that I would not like to base any scientific work upon progressive trials so made.

I have tested this log method in our experimental tank, and we found that the disturbance in the water due to the vessel passing through it extends such a great distance all round the vessel, that the proposal to fix propeller logs to a vessel must give fallacious results.

Having obtained the data, the next thing is to have it recorded in a proper form. I give you examples of the various methods adopted by my firm.

The first is the ordinary speed and power curve (see Sheet I). From this sheet you have the speed for any power, the revolutions for any speed, the Admiralty constant for any speed, slip in knots and slip per cent.

Another method of plotting these results is by what is known as Kirk's analysis, a method invented by the late Dr. Kirk, and communicated to the Institution of Naval Architects in the year 1880. He reduced the vessel to a prismatic body, in which the moulded length and draught are as in the full ship; the breadth is found by multiplying the real moulded breadth by the midship-area coefficient, and the length of en-

trance at either end is found by multiplying the real length by the prismatic coefficient and subtracting this figure from the length.

I give you an example of how this is done (Sheet II), and a sheet showing how the results are used (Sheet III).

This method gives a rough approximation to the real immersed surface, and the curves used with this method are called rate-curves. These consist of the I.H.P. at the various speeds divided by the number of hundreds of square feet in Kirk's surface. I give you an example of such a curve on Sheet IV.

Sheet V is the same as Sheet III, except that all the ships are reduced to a standard length of 100 feet by Froude's law. This is a very useful method, as it makes the decision of the rate more easy. Several methods of investigation of a similar nature have been proposed ; among others, notably one by Mr. J. Denholm Young, Wh.Sc. (see the Transactions of the North-East Coast Society of Engineers and Shipbuilders).

Previous to having the use of our tank this was the method that we invariably used, and we checked the result by Admiralty coefficient. After all, however, both these methods are uncertain, requiring a great deal of data to base upon, a considerable amount of experience in estimating, and a certain intuition in deciding on the correct factors.

My firm have been either particularly accurate or peculiarly fortunate, because it is a fact that we have never failed in giving the speed required. On the other hand, I must confess that the ship-owner has very often got from us much greater speed than he bargained for.

My brother, Mr. Wm. Denny, was so much impressed by the value of tank experiments that in the year 1882 he decided to construct an experimental tank for the firm.

It would make my paper too long to go into the detail of the construction of this tank, but full details will be found in Mr. Froude's paper of the different machinery used, and the method of using it.

It has been suggested that a co-operative tank should be laid down on the Clyde, and my opinion was asked upon the subject. I replied, that I had no doubt it would be valuable for the operator who ran it, but that the ship-building shareholder would profit little by it. The largest number of

models which we have ever been able to construct and run in one year is thirty-eight, and sometimes we could well employ two or three tanks when an important question is under investigation. It will thus be seen that few builders could expect much advantage from a tank unless all the data obtained were available for each, and I am afraid that the magnanimity of rival builders would not stretch to this extent.

Again, a tank is quite useless unless you have tried in it models of vessels already built, and for which the results of progressive trials are available. For the first two or three years after we had the tank, we were engaged principally in running what I may call "back steamers," that is, models of ships for which we had full data. Until we had thoroughly investigated these models we had no data from which to take our efficiencies; these efficiencies, or ratios of E.H.P. to I.H.P., being essential for the prediction of future speed results.

As I have said, I need not detail the method of investigation by models; it must be well known to most of you, and those who wish to study it more closely can obtain all the necessary information by referring to the late Mr. Froude's numerous papers, which have been read before the Institution of Naval Architects, and to those of his son, Mr. R. E. Froude, who has ably followed in his father's footsteps. I think, however, it will be of interest if I place before you two curves of resistance—one for a very full vessel, and the other for a fine vessel (see sheets VI and VII). You will observe that those for the full vessel are strongly marked by humps, while on the fine vessels these humps are less apparent, although still there. It is due to these humps that many failures in speed occur. In making the estimate the curve was assumed to be a fair curve; but in the actual ship, such not being the case, the vessel failed to obtain the speed predicted.

It may interest you to know that to produce these two sets of curves five hundred experiments were made, each corresponding to two double runs on the measured mile.

The tank is useful in many other ways, notably in the case of paddle-steamers. Had it not been for the tank, we should never have constructed the "Princess Henriette" and "Princess Josephine;" at least we would not have had the same assurance in taking the contract under such stringent

conditions as we did. These vessels, as is well known, were only 300 feet long, and on a draught of 8′ 6″ the mean speed was 21.1 knots, a speed which was quite unprecedented on this length and draught in the commercial marine. Since then we have built numerous fast paddles, and always with entire success. Unfortunately a monopoly of such a kind is impossible, but I feel that the success of Clyde builders in fast paddle-steamers is largely due to the tank.

To give you an idea of the work involved by such a problem: before making the contract we worked for three months in the tank, and subsequent to the contract we spent six months more in the investigation of the problem, and it is not even yet complete. We made no fewer than twelve models for the "Henriette," and three pairs of wheels, all of which were tried in the tank.

The total number of experiments made with these models was 2262, including those with the wheels, which alone numbered 891; of these experiments 1573 were made before the vessel was complete, of which 555 were wheel experiments, and the remainder, 689, were made to further investigate the problem. Although it is now five years since this vessel was delivered, I have just ordered a new set of experiments which will probably amount to as many again. The first experiment we made in our tank Feb. 21, 1883; and now, July, 1893, the number is over 40,000.

For absolute success in fast paddles the tank is essential, if for nothing else than fixing the exact position and height of the wave in way of the paddles.

Mr. Froude uses what he calls the constant method for analyzing his results; on the other hand, I found that this method would not suit my way of working. All the models we make have a standard length of 12 feet; they are tried at not less than five different draughts, and the results are plotted as rate-curves by Kirk's analysis, assuming an efficiency of 50%, and a vessel 100 feet long.

To use these curves I adopt an exactly similar method to that shown on Sheet III. The only assumption we have to make is the efficiency: this is not a great difficulty in view of the vast amount of data we now possess.

We always, however, check our results by Admiralty constant properly applied, and, where any doubt exists, by the

ordinary method of Kirk's analysis for full-sized vessels already tried.

We are now entering upon the subject of tank analysis of screw-propellers by means of the screw truck, of which you will find a full description in Mr. Froude's papers. Paddles, although treacherous, are comparatively an easy problem when compared with screw-propellers; but I look forward to great success and much interesting work in this investigation, although it will take years to investigate even the fringe of this vast subject.

In conclusion, I can only say that with all the information we have, and the facilities such information gives us for an accurate prediction of speed, we always think it wise to have at least a quarter of a knot "up our sleeve;" but we are not satisfied unless we get that quarter of a knot, and I am sure that as we progress in our investigation we shall find less and less need for this margin of speed.

I feel that my paper is scarcely worthy of this great congress. It contains nothing very original, but I have done my best to make it useful to you by using as examples in the various sheets figures taken for our most successful steamers. If its contents is "piper's news" to the older members of the profession, it may prove useful to the younger generation.

Sheet I.

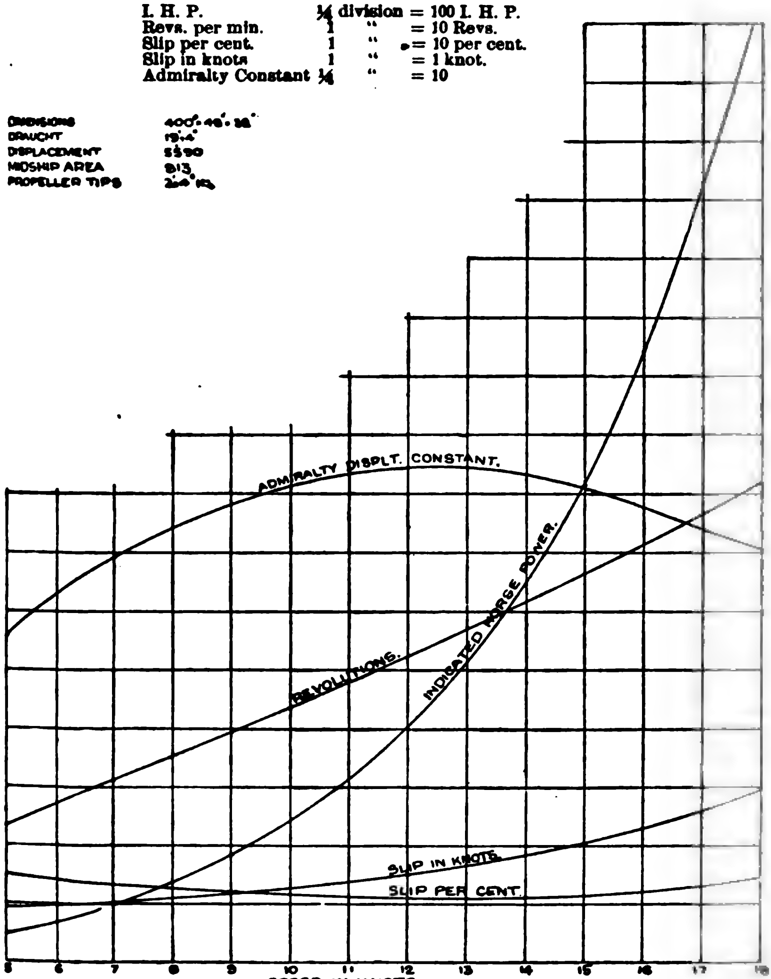
SINGLE SCREW. PASSENGER STEAMER

CURVES OF I.H.P., REVOLUTIONS, SLIP &c.
OBTAINED AT SPEED TRIAL ON MEASURED MILE.

SCALES.

I. H. P.	¼ division	= 100 I. H. P.
Revs. per min.	1 "	= 10 Revs.
Slip per cent.	1 "	= 10 per cent.
Slip in knots	1 "	= 1 knot.
Admiralty Constant	¼ "	= 10

DIMENSIONS	400'·48'·38'
DRAUGHT	19'·4"
DISPLACEMENT	5590
MIDSHIP AREA	813
PROPELLER TIPS	2'·4" in.

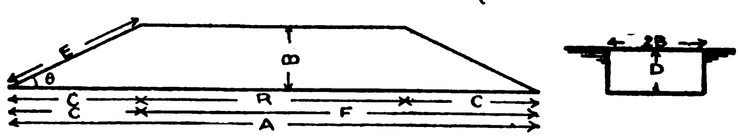


Sheet II.

CALCULATION INVOLVED IN KIRKS ANALYSIS.

PARTICULARS OF PROPOSED STEAMER

MOULDED DIMENSIONS.	360'·45'·29'6"
MOULDED DRAUGHT.	18·6'
DISPLACEMENT. Δ	5110 TONS.
MIDSHIP AREA $\otimes$	786 SQ. FEET.



$F = \frac{5110 \times 35}{786} = 227 \cdot 5$ $C = A - F = 360 - 227 \cdot 5 = 132 \cdot 5$

$B = \frac{786}{2 \times 18 \cdot 6} = 21 \cdot 13$ $R = L - 2C = 360 - 265 = 95 \cdot 0$

TANGENT OF ANGLE $= \frac{B}{C} = \frac{21 \cdot 13}{132 \cdot 5} = \cdot 1595$ ANGLE $= 9^\circ\text{-}4'$

$E = C \times \sec 9^\circ\text{-}4' = 132 \cdot 5 \times 1 \cdot 0127 = 134 \cdot 2$

BOTTOM SURFACE $= 2 \times B \times F = 2 \times 21 \cdot 13 \times 227 \cdot 5 = 9614$

SIDE " $= 2(R + 2E)D = 2 \times (95 + 268 \cdot 4) 18 \cdot 6 = 13516$

$\underline{23130}$

PRISMATIC COEFFICIENT $= \frac{\Delta \times 35}{A \times \otimes} = \frac{5110 \times 35}{360 \times 786} = \cdot 632.$

$\otimes$ AREA " $= \frac{\otimes}{45 \times D} = \frac{786}{45 \times 18 \cdot 6} = \cdot 939.$

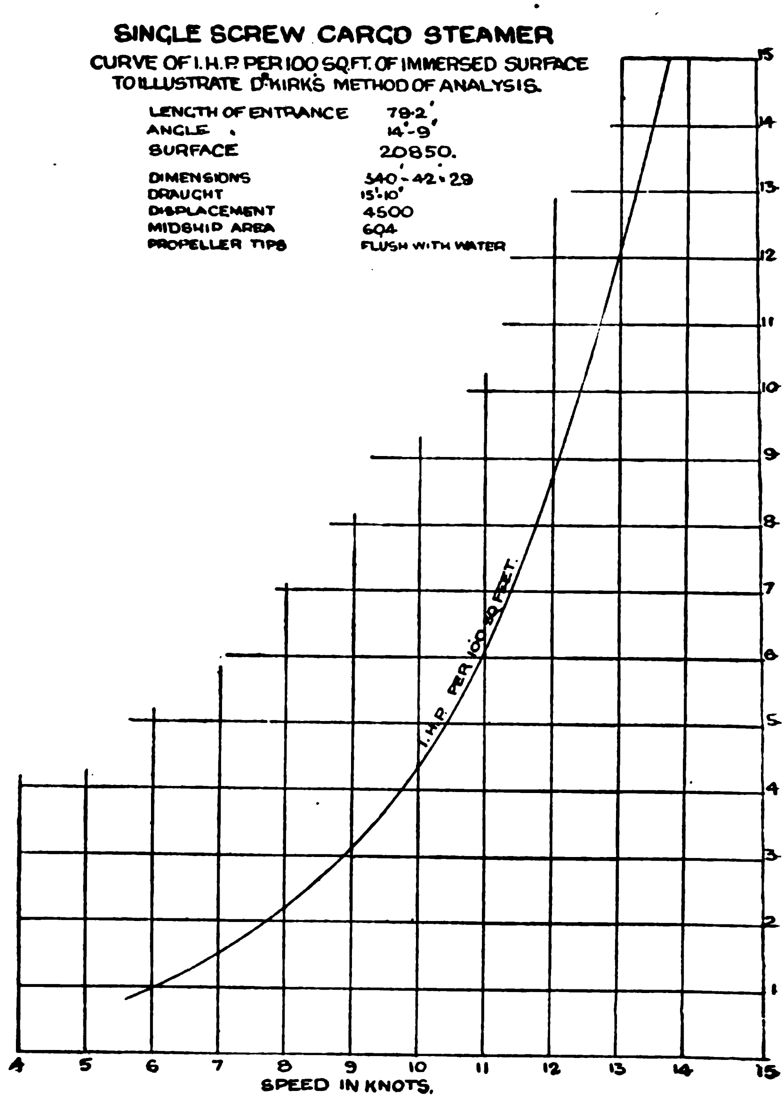
BLOCK " $\left(= \frac{\Delta \times 35}{A \times 45 \times D} = \frac{5110 \times 35}{360 \times 45 \times 18 \cdot 6} = \cdot 593\right)$

Sheet III

SPEED ESTIMATE S.S. 360'×45'×29'6.

		PROPOSED S.S.	TYPE S	TYPE S	TYPE S	TYPE S
LENGTH MOULDED	L	360'	360'	390'	400'	400
BREADTH	B	45'	45'	42'	43'9"	50
DRAUGHT	D	18·6'	19·0'	18·0'	20·0	19·75
DISPLACEMENT	Δ	5110	5656	5515	5720	6558
MIDSHIP AREA		786	802	719	795	860
PRISMATIC COEFFT		·632	·686	·688	·629	·647
MIDSHIP AREA		·939	·938	·952	·909	·899
BLOCK		·593	·643	·655	·571	·581
$\frac{L}{B}$		8·00	8·00	9·29	9·14	8·00
$\frac{D}{B}$		·413	·422	·429	·457	·383
LENGTH OF ENTRANCE		132·5'	113·2'	121·6'	148·2'	141·2'
ANGLE		9°·4'	10°·34'	9°·20'	7°·38'	9°·5
SURFACE		23120	24250	24870	26110	27070
RATE AT 15¾ KNOTS		16·2	17·5	18·10	16·2	14·50
I.H.P.		3750	—	—	—	–
WEATHER AT TRIAL		—	FINE	FINE	SQUALLY	FINE
$\frac{V^3 \times \Delta^{\frac{2}{3}}}{\text{I.H.P.}}$		$\frac{3546 \times 297}{3750} = 281$	[illegible]	[illegible]	—	

Sheet IV.



SINGLE SCREW CARGO STEAMER
CURVE OF I.H.P. PER 100 SQ.FT. OF IMMERSED SURFACE
TO ILLUSTRATE Dr. KIRK'S METHOD OF ANALYSIS.
LENGTH OF ENTRANCE 78·2'
ANGLE 14°-9'
SURFACE 20850.
DIMENSIONS 340'-42'-29
DRAUGHT 15'-10"
DISPLACEMENT 4500
MIDSHIP AREA 604
PROPELLER TIPS FLUSH WITH WATER
I.H.P. PER 100 SQ FEET.
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
4
5
6
7
8
9
10
11
12
13
14
15
SPEED IN KNOTS.

Sheet V.

SPEED ESTIMATE. S.S. 260′ × 32′ × 22·3.

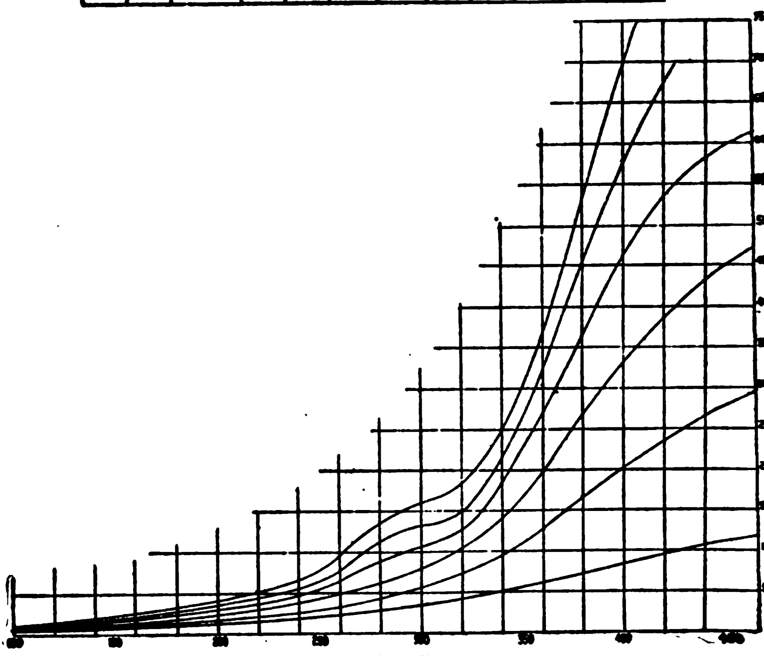
	PROPOSED S.S.	(REDUCED TO 100′ LENGTH)	TYPE S. "A."	TYPE S. "B"	TYPE S. "C"	TYPE S. "D"
LENGTH MOULDED L.	260′	100′	100′	100′	100′	100′
BREADTH B	32′	12·31′	12·6′	13·11′	15·65′	15·65′
DRAUGHT D	12·54′	4·82′	5·81′	4·92′	4·28′	4·09′
DISPLACEMENT	2208	125·6	163·0	132·6	135·8	129·0
MIDSHIP AREA	385	57	71·2	61·6	63·5	60·7
PRISMATIC COEFFT	·772	·772	·803	·755	·749	·744
MIDSHIP AREA	·959	·959	·969	·955	·949	·949
BLOCK	·740	·740	·778	·721	·711	·706
$\frac{L}{B}$	8·12	8·12	7·90	7·61	6·39	6·39
$\frac{B}{D}$	·392	·392	·460	·375	·273	·261
LENGTH OF ENTRANCE (KIRK'S ANALYSIS)	58·3′	22·8′	19·7′	24·5′	25·37′	25·57′
ANGLE (KIRK'S ANALYSIS)	14°·31′	14°·31′	17°·15′	14°·20′	16°·22′	16°·11′
SURFACE (KIRK'S ANALYSIS)	12780	1891	2168	1946	1985	1940
RATE FOR 100′ SHIP ([illegible])	–	2·72	2·59	2·51	2·89	2·77
RATE FOR 260′	11·40	–	10·85	10·53	12·11	11·64
I.H.P. (AT 12½ KNOTS)	1457	–	–	–	–	–
WEATHER ON TRIAL			FINE	FINE	FINE	FINE
$\frac{V^3 \times \Delta^{\frac{2}{3}}}{I.H.P.} =$	$\frac{1953 \times 169}{1457} = 226$		—	—	—	—

Sheet VI.

FULL MODEL

1905 & '06

DATE	TEMP	No. OF EXPTS	MODEL	LENGTH	MLD. BREADTH	MLD. DRAUGHT	DISPLT	⊠ AREA	SKIN	COEFFTS. PRIS.	COEFFTS. ⊠ AREA	COEFFTS. BLOCK
10-20-12 10-12-5	49 & 50 ·	11710–11782 13677–13734	50	12	2 4	1·32'	1906	3·079	52·96	·886	·972	·803
26-29-12 14-17-5	49° 48°	11783–11810 13745–13788	·	·	·	1·1'	1555	2·56	47·10	·815	·966	·787
[illegible]	49°	13789–13830	·	·	·	·9'	1239	2·073	41·95	·798	·960	·766
[illegible]-5	49° & 50	13937–13975	·	·		·7'	928	1·595	36·65	·777	·949	·738
26 & 27-5	50°	13976–14086	·	·	·	·45'	536	·988	30·15	·751	·915	·687
1 & 2-6	60°	14087–14116	·	·	·	·2	210	·400	23·0	·728	·833	·607

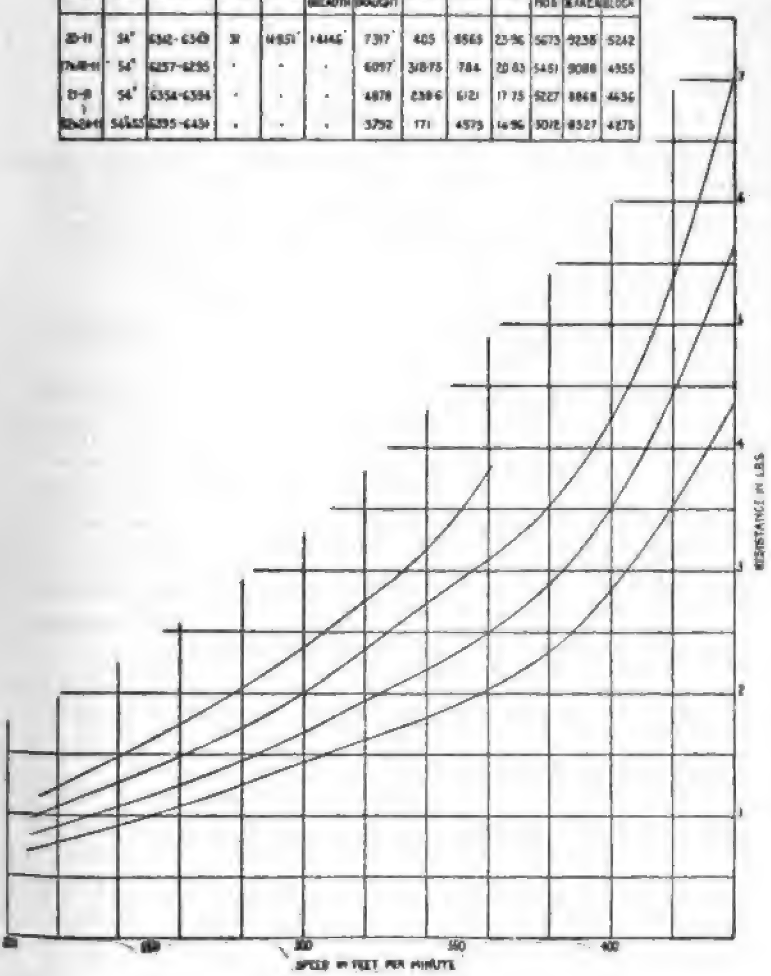


Sheet VII.

FINE MODEL

1894

DATE	TEMP.	[illegible]	MODEL.	LENGTH	MLD BREADTH	MLD DRAUGHT	DISPLT	⊗ AREA	SKIN	COEFFTS PRIS	⊗ AREA	BLOCK
20-11	54°	6342-6349	31	14·851'	1·4146'	·7317'	405	·9565	23·96	·5673	·9238	·5242
17&18-11	54°	6257-6295	"	"	"	·6097'	318·75	·784	20·83	·5451	·9088	·4955
21-11	54°	6354-6394	"	"	"	·4878	230·6	·6121	17·75	·5227	·8868	·4636
22&24-11	54½&55°	6395-6431	"	"	"	·3752	171	·4575	14·96	·5012	·8327	·4275



XXXII.

SPEED TRIALS AND AN APPARATUS FOR ACCURATELY RECORDING REVOLUTIONS AND TIME ON THE MEASURED MILE.

By WILLIAM D. WEAVER, Esq.,

Electrical Engineer, formerly of the Engineer Corps, U. S. Navy.

In this paper speed trials will be considered more particularly with reference to naval vessels, though what is said will be more or less applicable to merchant vessels as well. Owing to the practice of the U. S. Navy Department in paying enormous premiums to ship-builders for excess of contract requirements, even on vessels designed in the Department and constructed under minute specifications whose fulfilment is guaranteed through constant and rigorous inspection by its officers, the subject of exact speed trials has become one of unusual importance. That exactness is desirable may be judged from the fact that premiums amounting to over $30 per foot, or $1100 per second, have been paid by the Navy Department.

Speed trials may be classified, according to their object, as contractors' trials, trials upon which to base cruising speeds, and trials to obtain data for designing purposes. For the last two the measured-mile course is obviously the best; for the former, two methods that have been used in the United States Navy will be considered, one over a measured course of such a length as to require at least half the contract time to make a run each way, and the other based upon a continuous run at sea and the speed determined from the average

revolutions made by reference to a curve of speed and revolutions determined before or afterwards by accurate observations during progressive trials over a measured-mile course.

While the former method is the most direct and therefore appeals particularly to the non-technical mind, there are a number of objections to it, among which are the following:

1st. Difficulty of finding a trial course of necessary length in water of proper depth that will be in sufficient proximity to land to establish ranges;

2d. Greater difficulty, as compared with a well-selected and laid off measured-mile course, in observing ranges;

3d. Difficulty of determining the strength of tide;

4th. Uncertainty in the tidal correction on account of the direction of tide with relation to ship;

5th. Complication due to the existence of a surface current in large bodies of water;

6th. Liability to error due to personal errors of a large number of tide observers with, presumably to many, unfamiliar apparatus;

7th. Expense from the large number of vessels necessary to have on the trial course (there were seven on the trial of the U. S. S. "Philadelphia");

8th. The length of time necessary to gather the observing fleet and inconvenience caused by taking so many vessels from other duties;

9th. Unreliability on account of necessary haste in taking the few range observations, and the considerable personal error involved in the same;

10th. The personal element in interpreting and applying tide corrections;

11th. The delay that may arise from the necessity of awaiting favorable weather;

12th. The opportunity afforded contractors for claims, in case of failure, that the course steered was devious, the ranges were not properly taken, the tide improperly taken or applied, etc., all of which would be difficult to contest on account of the absence of unquestionable records.

The other method for contractors' speed trials referred to, which has been advocated by Engineer-in-Chief Melville and was successfully applied on the trial of the U. S. S. "Bancroft," consists in running the vessel over a measured-mile course at

different rates of speed, accurately observing the time and revolutions for each speed, and plotting a curve from these data; the vessel is then run at sea during the specified contract time, the average revolutions determined, and the corresponding speed taken from the measured-mile speed and revolution curve.

The only objections that the writer is aware of that have been urged against this method are:

1st. It is not sufficiently obvious to the untechnical;

2d. Conditions as to draught and cleanness of bottom are required to be the same on the measured-mile and final trials;

3d. Great accuracy in time and revolution measurements is required on the mile trials.

As the final trial will in all cases take place very soon after or before the measured-mile trials, the objection in regard to the condition of the bottom has little weight, and it is a matter of little difficulty to keep the trim and draught the same. As to accuracy of measurement, the recorder that will be described later enables this to be secured to a high degree, with the introduction of a minimum personal element.

Among the advantages that have been urged in favor of this method are the following:

1st. The speed and revolution curve is not only secured to a great degree of accuracy, including the elimination of tide effect, but a permanent record of the speed and revolutions is obtained that can be placed in evidence in case of dispute;

2d. The same curve furnishes data for cruising purposes, and exact data for designing purposes that otherwise in only rare cases would be obtained, owing to the general absence of progressive trials for that purpose;

3d. But few observers and attendants are required on the mile trials—three are sufficient—and on the final trial observations of revolutions alone are necessary;

4th. Considerable errors in taking the first and final observations of revolutions on the final trial will not appreciably affect the result;

5th. On the measured-mile trials personal errors, besides being reduced to a minimum, may be easily rectified, if discovered, without serious delay, and there is scarcely any conceivable chance of error, with ordinary precautions with the counters, on the final trial;

6th. The measured-mile trials need not exceed a day or two days at most, no assistance is needed outside of the ship, and the final trial need not be hindered by hazy conditions of weather that would delay a trial over a measured course;

7th. The final run can be made at sea under the best conditions instead of under the circumscribed ones inherent with the other method;

8th. The result of the final trial is known a few minutes after the trial is ended, there being no calculations nor corrections to apply.

The details of measured-mile trials need scarcely be referred to here, as they are sufficiently well known in general, and have been treated in great detail by Naval Constructor David W. Taylor, U. S. N., in a valuable paper in Vol. IV (No. 4) of the *Journal of the American Society of Naval Engineers.* Attention will merely be called to the necessity of the ship having a sufficient distance for getting up to speed before entering on the course, which should with large ships be over a mile. There is reason to believe that with a ship like the "Lepanto" the necessary distance in which to increase the speed by two knots is not far from two miles; it is in attaining the last tenth of a knot that the proportionate distance is the greatest. (See "Some Problems in Propulsion," by the writer, in Vol. I (No. 1) of the *Journal of the American Society of Naval Engineers.*

It should also be remembered that indicator errors, if uncorrected, may so vitiate the power data as to render the scientific results deduced from them entirely misleading. Extensive experience in the exact testing of indicators at the New York Navy Yard has shown that errors of five per cent, and even more, may exist in indicators of good grade, and three per cent may perhaps be considered a usual error. An electrical arrangement very simple to make and apply, of which one of the best forms is that devised by A. M. Mattice, Esq., can be attached to the indicators so that cards may be taken simultaneously at a given time.

The recorder referred to was designed for taking accurate records of time and revolutions on measured-mile trials, and is illustrated with fac-simile of records and a diagram of connections. An ordinary chronograph was first suggested, but the delicate nature of such instruments and the great expense

of one suitable for use aboard ship made its adoption impracticable. While making inquiries about forms of chronographs it was learned that a number of Morse registers had been fitted with two pens for use as chronographs in college laboratories, and following the suggestion the present apparatus was devised.

While in principle a Morse register, it differs in being more carefully constructed; in having a governing attachment by means of which the speed of the paper may be varied; in having five pens instead of one, and in the method by which motion is given to the pens by the magnet armatures. The essential principles of the apparatus are as follows:

By means of a clock train a paper tape is passed above the pens on which, at each electrical contact, a mark is made by one of the latter. To an arbor of the train is attached one of several inertia governors, by means of which the speed at which the tape is paid out can be regulated. In the apparatus made for the U. S. Government there were three of these, one permitting a speed of one-half inch per second, another of one inch, and the third of one and one-half inches. Running free, the tape has a speed of about two and one-half inches per second.

In order that the speed may be as regular as possible, a Geneva stop is connected to the barrel of a very long main spring, so that only that part of its elastic force may be utilized which is approximately constant. It should be remembered, however, that the requirement for which the instrument is used is that the speed of the tape shall not appreciably vary during any second, so that a considerable total variation during the entire time it is running will not be significant if reduced to a second.

The five pens are actuated by four magnets. To one of the magnets is led the interrupted current of a chronometer, to two others the currents established by contacts on the port and starboard shafts respectively, and through the fourth a momentary current is passed at the instant of arriving on and leaving the measured-mile course. To the armature of the latter are connected two pens which mark on the two margins of the tape, thus permitting the datum line to be drawn from which are measured the fractional parts of time and revolutions.

The instrument will run out one hundred and twenty-five feet of tape with very little variation of speed; this, with the inch-per-second governor, corresponds to a time of twenty-four minutes. The tape may be measured to give hundredths of an inch and, with a shaft making one hundred and twenty revolutions per minute, fiftieths of a revolution.

An essential feature is the "piano action" of the pens. Through this the time of contact of the pen is infinitesimal, thereby avoiding friction against the tape at a critical moment; the range-observer, for example, can keep the key depressed after passing the range, but the pen will drop free from the paper after instantaneously having made its mark. The only precaution necessary is to see that the pens are so adjusted that no mark will be made on the moving tape if the respective armatures actuating them are held successively against their magnet poles; a pen should only mark through inertia throwing it beyond this adjusted position when electrical contact is made, as otherwise the friction on the tape will vary the speed of the latter and thus vitiate the result—seriously so in the case of the range pens.

The instrument is by no means a delicate one, but will stand even rough usage. Owing to the powerful spring and few arbors in the train the probability of derangement is small. During considerable experimenting, and also on the trial of the U. S. S. "Bancroft" I am informed, no hitch whatever has occurred.

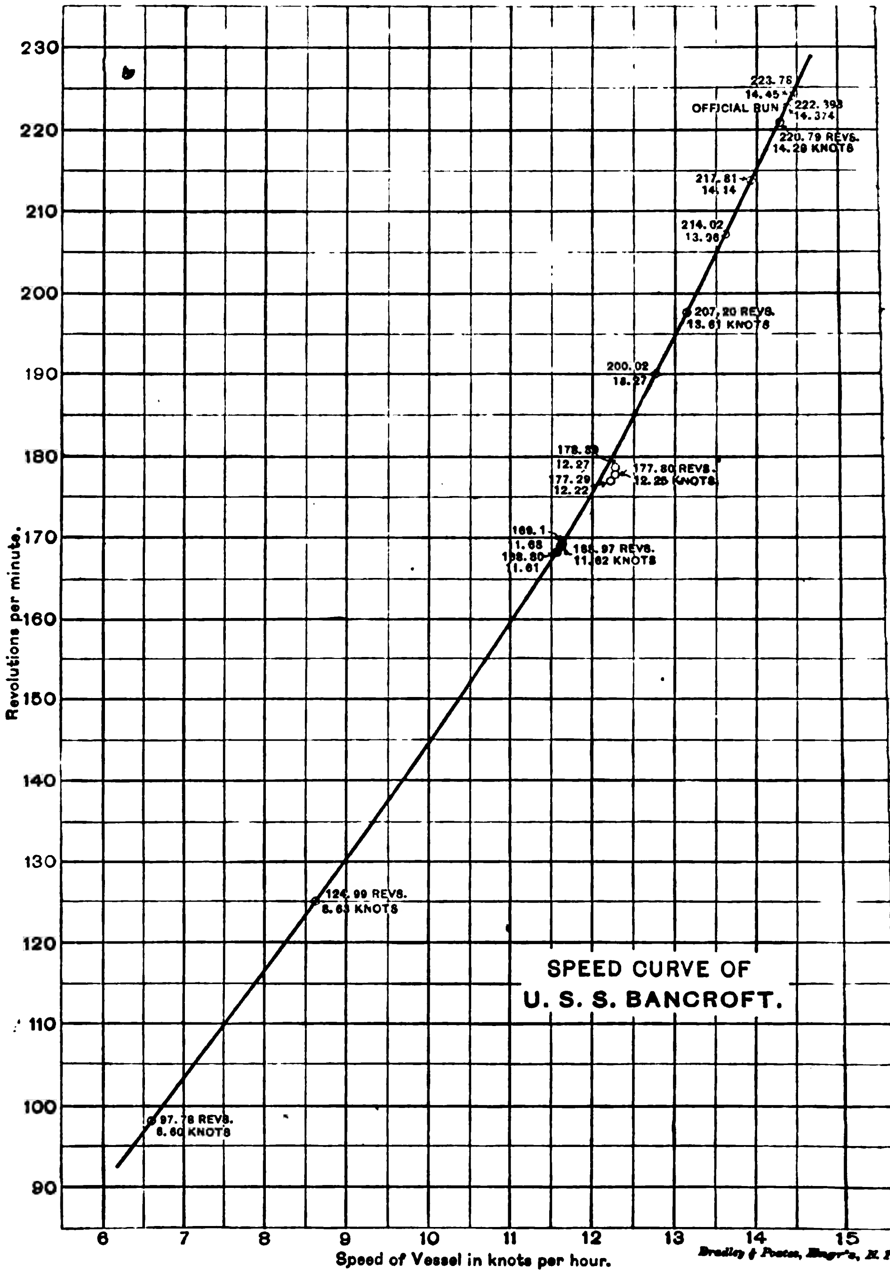
For trial trips there may be three range-observers to check each other (although two are sufficient), one at the bow, another amidships, and a third on the poop. As the ship enters or leaves the range course, the observer touches a key and a record will be made on the tape. The diagram of connections shows key-boards, held by the observers, on which there is also an electric-bell connection to notify, from twenty to thirty seconds before the ship enters her course, the one in charge of the instrument that he may set it in motion and switch on the battery. The same diagram makes clear the circuits, etc.

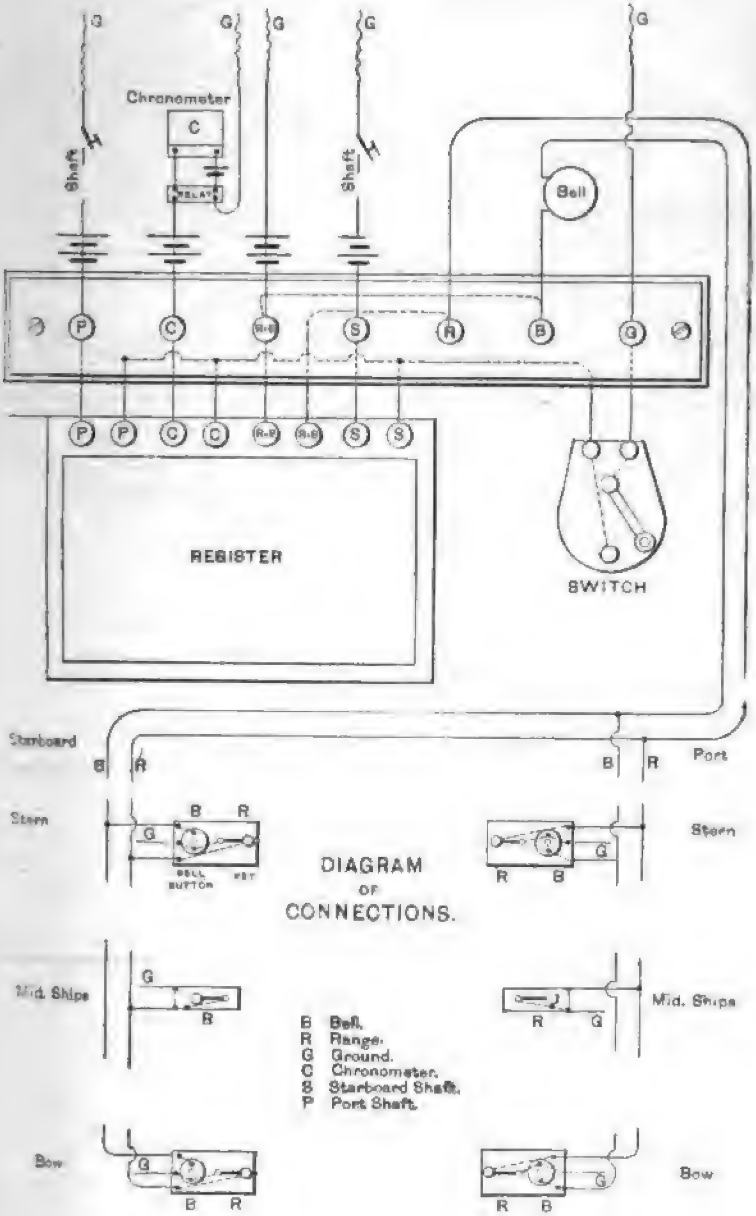
Fac-similes of records are given, taken from shafts revolving at the rates of about 120, 400, and 1000 revolutions per minute. The method of determining the fractional part of time or revolutions is simple, being the ratio of the part of an

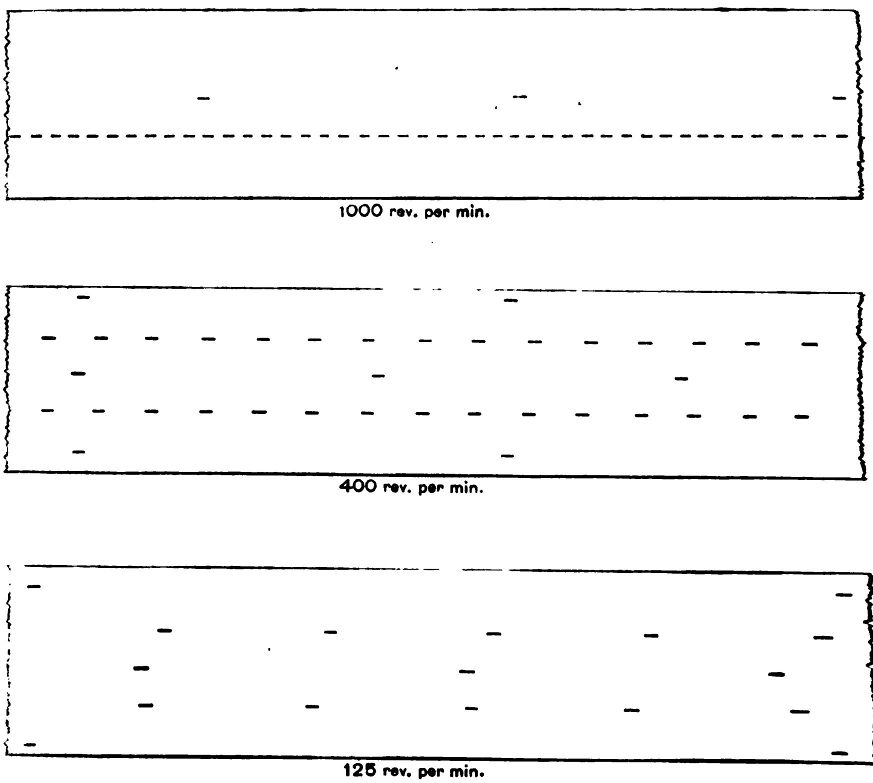
interval intercepted by the datum line and the whole interval. Only the fractional and one whole interval at each end of each record are measured, the other whole intervals being simply counted. The chronometer relay shown in the diagram of connections is merely that only one cell may be connected with the electrical chronometer, and the connection board was devised so that it would be difficult to make any mistake in connecting the recorder and the circuits, cells and chronometer.

While the accuracy of the instrument may be greater than is really necessary, it is attained at no sacrifice and renders it useful for other purposes. At the launch of the U. S. S. "Texas" the instrument was used to get the speed of launching, thus enabling the coefficient of friction to be very accurately determined.

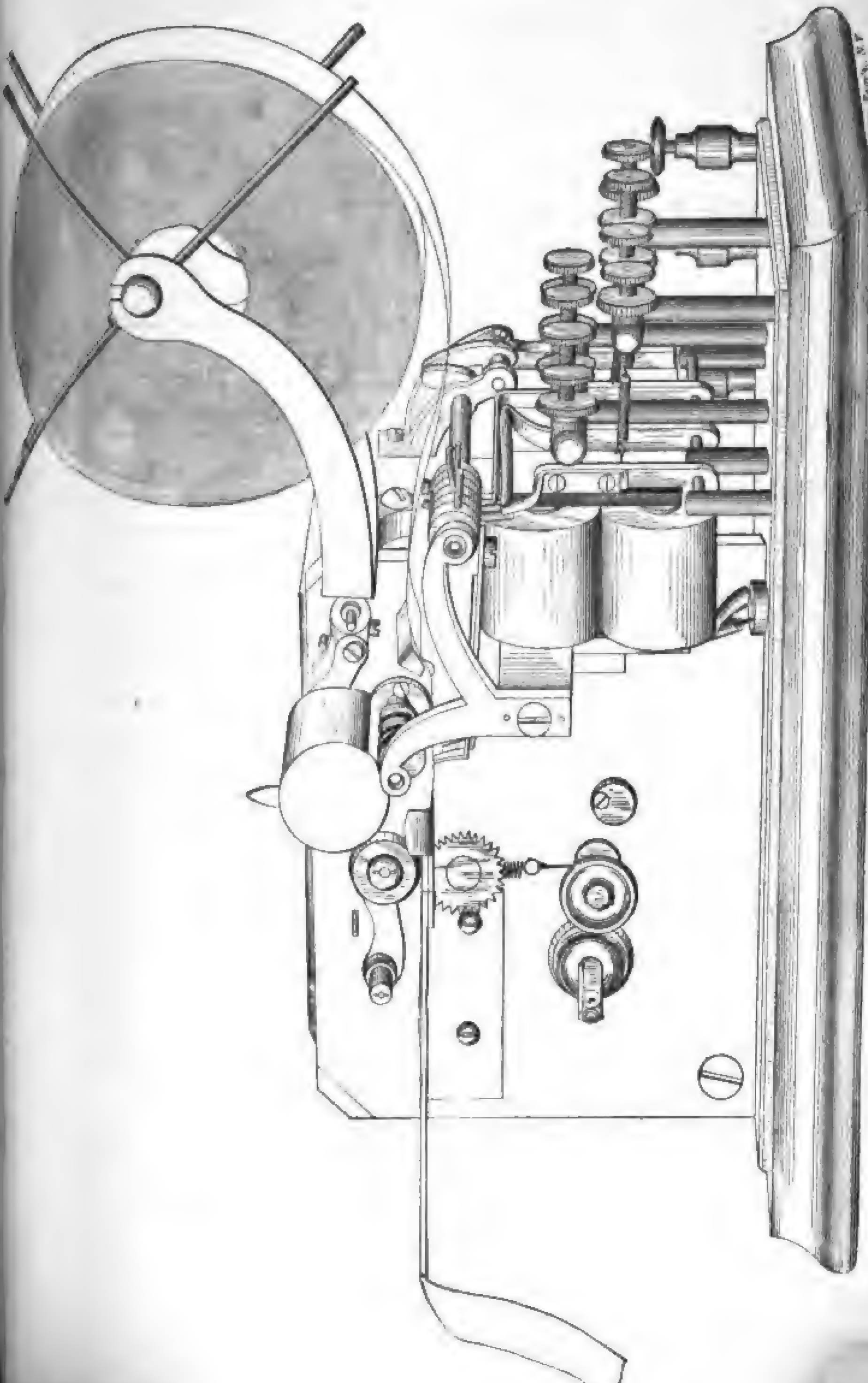
A reproduction of the curve obtained from the measured-mile trial of the "Bancroft" by means of the recorder described, is appended.


SPEED CURVE OF
U. S. S. BANCROFT.
Revolutions per minute.
Speed of Vessel in knots per hour.
230
220
210
200
190
180
170
160
150
140
130
120
110
100
90
6
7
8
9
10
11
12
13
14
15
OFFICIAL RUN
220.79 REVS.
14.29 KNOTS
207.20 REVS.
13.61 KNOTS
200.02
177.80 REVS.
12.27
12.22
124.99 REVS.
97.78 REVS.
Bradley & Poates, Engr's, N. Y.


G
G
G
G
G
Chronometer
C
RELAY
Shaft
Shaft
Bell
P
C
R-B
S
R
B
G
P
P
C
C
R-B
R-B
S
S
REGISTER
SWITCH
Starboard
B
R
B
R
Port
Stern
B
R
G
BELL BUTTON
KEY
Stern
R
B
G
DIAGRAM
OF
CONNECTIONS.
Mid. Ships
G
B
Mid. Ships
R
G
B Bell.
R Range.
G Ground.
C Chronometer.
S Starboard Shaft.
P Port Shaft.
Bow
G
B
R
R
B
G
Bow



FAC-SIMILES OF RECORDS.



DISCUSSION OF PAPERS BY MESSRS. DENNY AND WEAVER ON SPEED TRIALS.

MR. E. PLATT STRATTON:—I have not had the personal pleasure of reading over this paper of Mr. Denny, but I believe he lays down the principle of testing vessels by trials of distances of one mile. This may give a demonstration of a vessel's actual speeed over such distance, but I do not think it is calculated to prove endurance or efficiency under all the varying conditions of a longer period. The vessels that have been built in this country during the last few years have invariably been tested for four hours, and our Government recognizes no test of endurance of less than that, which I believe to be the prevailing requirement of the Navy Department. Were we to try our vessels upon the basis of speed over a single mile only, I do not think it would be accepted as a fair trial of efficiency, and I am glad to know that such a custom does not prevail.

SECRETARY McFARLAND:—I am afraid that our friend Stratton does not thoroughly understand the method of these measured-mile trials. It is not a single run over one mile, but it is a series of runs. It is not a thing that is done in five minutes or even in two minutes; but to make a proper series of runs, even at high speed, involves at least an hour, and there is no question about the accuracy; the speed thus found is certainly the speed of the ship beyond question, and the method is a thoroughly and accurately reliable one for getting the speed. It does not mean that, if the vessel can make that distance for one hour, the same speed could be maintained all day; but it does show that the vessel can make that speed for a given number of revolutions of the engine.

MR. STRATTON:—I recognize that the purpose was to standardize the speed, but as a run over a measured mile—I did not understand so by Mr. Denny's paper.

MR. JOS. R. OLDHAM:—I think Mr. Stratton is possibly not well acquainted with the *modus operandi* of the measured-mile trial. The mile trial is quite usual, but is always supplemented by a six-

hours trial at sea, and I rather think that has been extended to something like ten hours; the measured mile is only a portion of the trial of the speed of the vessel, but even the measured-mile trials by the Admiralty are not such perfunctory performances as some suppose.

The day of trial is fixed and the steamer proceeds to sea, *rough* or fine; she steams continuously for some time, and then goes on the mile course; she then steams continuously over that course, making six double runs, and that without a stop. On the occasion referred to, our measured *mile* trial meant a continuous test of machinery and hull over a distance of about 20 knots.

Mr. Raynal:—I have been looking around in vain for some of the naval officers that were with us on the trial-trip of the "Bancroft," in hopes to hear from them. This trial-trip is of more than usual interest to us, as it is the first official contract trial that was made in this country over the measured mile, after the plan suggested by Commodore Melville. I wish to tell Mr. Stratton that the trial over the measured mile was entirely distinct from the endurance trial. There was an endurance trial of four hours afterwards, but the first trial over the measured mile was merely for standardizing of the screw-propeller. The success of that trial was something marvellous to me. The way in which the various results tabulated and tallied with the fair line afterwards laid out was magnificent. You can all see it by consulting the last issue of the Journal of the Society of Naval Engineers.

As to the results for contractor as well as government official, I cannot imagine anything more agreeable. The contractor must necessarily have tried his engine to a certain extent at the docks, at least; he may have taken a run or two outside; he therefore knows what his comfortable speed is by the revolutions of the engines, and he is fairly presumed to know what his engine can do in the number of turns per minute; he does not, however, know what the knots are. He may throw a log overboard; he may take a good pilot with him, who has got a certain practical knowledge of speed, and come pretty close to it. When we went to Newport on the trial, we made four sets of trials over the mile in half a day. If we had started a little earlier we could have made that measured trial-trip in one day with the utmost comfort.

I am astonished to see in Mr. Denny's paper that he recommends starting at the highest speed and going down: I should think he would prefer the other way—starting from the lowest speed and going up.

Men who have experience at races, or have timed engines and

have good chronometer watches, are capable of splitting the second into quarters. I think it essential that the observers should have targets on the ship. We did not have them; I think these would be better to catch the points exactly from the ship.

As to steering, I think there is no difficulty with a good helmsman. Now with the modern instruments—I refer especially to the Weaver instrument—there is no difficulty about determining the exact time at which these different points of the mile are passed. In the engine-room there is no difficulty now in counting the revolutions exactly, and as we had already laid down some rough measurements, we knew at all times what speed we were making. A few minutes after the speed trial was run we had plotted our curves, and knew exactly what we could expect from our endurance trial the next day.

And now in regard to this endurance trial: it partakes, where premiums are involved, somewhat of the nature of a horse-race; and, gentlemen, who of you would like to go to a race, sit in a sulky and travel all round by yourself over the race-course, with a great big fence on the other side, not knowing what the other fellow does? That would be of no interest. It is just the same thing in the engine-room. You take your boat out, you go along for all you are worth, but you do not know what speed you are making. You may have a little something to spare ; if you knew how far off you were from your goal, maybe you would pinch a little harder; but, on the other hand, if you knew that you had reached the desired point, you would feel more comfortable, and not crowd your machinery unnecessarily.

Now on this trial of the "Bancroft" we knew exactly at any time what fraction of a knot we were driving that ship. There was not a horse-power question involved; it was merely a speed question. There was a premium for every quarter of a knot added to a speed of 12 knots. We knew every instant what we were doing; and that I consider by far a more interesting condition of running a race than to go it blindly. The Weaver instrument which we used was very satisfactory; and although it took a great deal of time to figure up the data from it afterwards, we found that our rough calculation tallied with it practically. I wish that all the engineers interested in this subject would look up the paper of Passed Assistant Engineer R. S. Griffin on the "Bancroft" trial, published in the *Journal of the American Society of Naval Engineers* for May, 1893.

DR. FRANCIS ELGAR:—With reference to Mr. Stratton's remarks upon the value of the measured-mile trials of ships, I think

it is only necessary to consider what a measured-mile trial represents, and what it does not represent; and those who are in the habit of conducting such trials, I think, know pretty well what they are worth. The trial of a ship upon the measured mile merely represents the relation of speed to power in that ship in absolutely smooth water. It does not represent anything less or anything more. The questions of how the speed is to be measured, and how the time is to be measured, are important; but still they are minor details. The fundamental point involved in the measurement of trial speeds is that the results should give the true relation of speed to power; and provided the observations are accurate, it gives you that relation in smooth water. The other trials that have been referred to, whether for four hours, six, twelve, or twenty-four, or what you like, give but little more information as to the relation of speed to power. Those trials are usually conducted in smooth water, and they also give the relation of speed to power in smooth water during the time over which they last. They help, however, to show further that the arrangements of the ship, the arrangements for working the engines, the arrangements for getting coal to the fires, and so on, are sufficient to enable the power to be maintained over the length of time during which the trial is made; but none of those trials furnishes a true measure of the average speed that the ship could be relied upon for maintaining at sea.

Mistakes may have been sometimes made in supposing that these trials represent more in that way than they actually do; but no one who has much to do with the speed of ships at sea could ever suppose that smooth-water trials would give the relation of speed to power that could be relied upon at sea. It is not necessary to go very deeply into the matter in order to learn that the form of ship which is calculated to give the best results on a smooth-water trial is not necessarily the best form for speed at sea. There is no exact relation between the speed of a ship with a given power on a smooth-water trial and the speed she will be able to maintain on the average with the same power at sea.

No doubt contracts for vessels intended to have very high sea-speeds have sometimes been made, in which the requirements for testing speed have been limited to smooth-water trials—and this inadequate test of power may possibly have been adopted under the supposition that the speed capable of being maintained at sea will be proportionate to the speed realized upon the smooth-water trials. This, however, is a fallacy, as experience has often proved. I know many ships whose speeds might be increased upon the measured mile by slight differences of power favorable to speed

in smooth water, but I believe it would be at the expense of their average performance at sea. It is not the ship that gives the best results at sea that will give the best measured-mile results, and there ought not to be any misunderstanding about that. It is only necessary, in dealing with the trials of ships, to remember exactly what they represent; and I should think no one would expect a ship to give the best speed results at sea merely because she does so in smooth water, any more than he would expect a fast racing-boat on a river to be the one best adapted for speed in rough water.

With regard more particularly to Mr. Denny's paper, I would like to say that I consider it extremely valuable and interesting. It embodies the results of a large amount of labor and experience in connection with model experiments and measured-mile trials. Messrs. Denny have been foremost in our country in this department of scientific and practical work, and they are the only firm that possess a tank and are able to make model experiments for themselves.

Mr. Denny has spoken of the establishment of experimental tanks for general use. This is a question that has been discussed among us at various times; but I think the general body of naval architects and marine engineers could in an easier way get the information they require for the practical work of designing. For instance, the British Admiralty have a vast amount of information respecting the resistances of a great variety of models of different forms and proportions, that has been accumulated during the progress of Mr. Froude's experiments; and if they would authorize the analysis and collation of the speed data contained in those results, a great deal of information might be published for the use of the shipping world that would be extremely valuable, and would to a great extent remove the necessity for independent model experiments. This was a point that was mentioned by Prof. Durand in connection with the discussion upon my paper. He then suggested that by conducting a series of experiments upon a graduated and systematic scale general results might be obtained in connection with the effect of dimensions and proportions upon resistance, and a great deal of useful data collected, such as might do away with the necessity for independent experiments. I think this would supply all that is needed by most naval architects and engineers; and I venture to suggest to the American members of this Congress that they urge upon their own government the great benefit it would be, not only to the Navy in estimating the speeds of war ships, but to the country at large, in promoting progress in the highest class of mercantile ship-building, if they were to organize an experimental

tank [applause] upon the lines so well worked out by Mr. Froude, and appoint a competent scientific staff to work it—for which they have all the necessary talent at their disposal. If the Navy Department were to see fit to establish such an organization, and carry out a systematic series of experiments such as that referred to, and publish the results, they would furnish most powerful aid to naval and mercantile ship-builders and engineers in questions relating to speed and resistance, and confer a great favor upon all who are interested in the scientific problems connected with the propulsion of ships.

MR. MCFARLAND:—Apropos of the remarks Mr. Raynal has made about the method by which the U. S. S. "Bancroft" was tried, and applying particularly to Mr. Weaver's paper, I want to say that this method of trial was devised by Engineer-in-Chief Melville, after very careful consideration of the problem presented by the contract trials of some of our U. S. naval vessels, where there was a large speed premium or penalty depending on very accurate measurements.

In these vessels the premium was $50,000 per quarter knot, but the contract was interpreted to mean that this quarter knot must be entirely completed in order that any of the premium should be earned; in other words, .24 of a knot would earn no premium, while .25 would earn $50,000.

Now in running over a measured course it is to be remembered that it is a rather troublesome thing to lay out forty or fifty miles on land where the error will be absolutely *nil*, and of course it is very much more difficult to do the same thing for a distance on the water; and, as is pointed out in Mr. Weaver's paper, it is extremely difficult to find a long course with sufficiently deep water near enough to shore to enable the ends of the course to be established by ranges, so that it has become necessary in some cases to establish the ends by buoys. I think very few of us would be willing to guarantee the exact location of a buoy within less than a hundred feet of an intended place. Now $\frac{1}{100}$ of a knot is only 60 feet, and consequently an error of even a few hundred feet in a long course might make all the difference between success and failure under the conditions I have already stated.

It was in view of all these facts that the Engineer-in-Chief was led to devise what has been called the standardized screw method, where the ship is run over a measured mile at a series of speeds, so as to be able to plot a curve of speed and revolutions. From this curve it is possible to tell at once what speed the vessel is making as soon as the average of the revolutions is known. It is to be noted, as an inherent advantage in this method, that by running the speeds

on the preliminary trial tolerably close together at the upper end of the curve, it will be possible to prolong the curve to an amount of about one knot above the highest speed actually observed without any appreciable error, so that if on the final trial the speed obtained was greater than any observed during the preliminary run, its value would still be capable of accurate determination.

The "Bancroft" is the only one of our vessels which has ever been officially tried by this method; but I believe I am right in saying that other contractors, after seeing the satisfaction with which the speed was determined in that case, were almost unanimously in favor of using that method for future trials, and I may mention in this connection that the fast Argentine cruiser, "Ninth of July," built by the Armstrongs, was tested in this same way, and I understand it is becoming a favorite in England. It is worth noting that the standardized screw method permits the four-hour or endurance trial to be run anywhere, so that the vessel could be taken out to sea in very deep water, where there would be no question of reduction of speed due to shoal water, and where, moreover, there would be no possibility of the trial being interfered with on account of passing vessels, fog, or other causes. This is specially brought to mind by the fact that on the recent trial of the U. S. S. "New York," when the horse-power came to be computed after the trial, it was found, curiously enough, that the maximum horse-power did not correspond to the maximum revolutions as would naturally have been expected, and this occurred twice in the course of the four hours. Passed Assistant Engineer Freeman of the Navy, in investigating this matter, found that the times at which these cards were taken were such that they corresponded to the position of the vessel in about the same place, although running the course in opposite directions; and on conference with the pilot of the vessel he found that at the time of this reduction of revolutions the vessel was in the shoalest part of the entire course.

At the risk of wandering a moment from the matter under discussion, I deem it important to emphasize this matter of the reduced speed, because there is so little information as to the exact depth of water necessary that there may be no reduction of speed due to insufficient water. The "New York" at this time was making 21 knots, and the depth of water at which the reduction occurred was 37 fathoms. I am free to say I had not previously believed that there could possibly be any reduction with so great a depth of water as this. In fact, I should have been prepared to say that 25 fathoms would have been ample depth to prevent any reduction of

speed. I call attention to this fact because I believe it gives valuable data.

I will add just a word with regard to the excellence of the recorder devised by Mr. Weaver while he was an engineer officer of the Navy. It was tried thoroughly on the "Bancroft" and afterwards on the "Detroit," although the trial on that occasion was not based on the record of the apparatus. It gave entire satisfaction in every case; so much so, that the officers using it were tempted to carry it beyond what it was directly intended for, and to attempt to get a record by it for the full four hours' trial. Without some such apparatus as this, it would not be possible to use the standardized screw method, and feel sure of the results with sufficient accuracy, because on a measured mile a difference of a small fraction of a revolution, or of a very small time interval, would make a considerable difference in the speed per hour as used in plotting the curve. Mr. Weaver displayed great ingenuity in devising the apparatus, at once simple and elegant, and I feel glad to bear testimony to its excellence.

PROF. WM. F. DURAND:—In connection with the admirable paper of Mr. Denny, I would mention a method for the application of tidal corrections which, so far as I am aware, has not as yet been used. As is well known, the proper application of these corrections is one of the most troublesome matters in connection with speed trials over a measured course, especially where the course is several miles long, and may therefore require so much time that the tidal velocity will be far from constant during the run.

The tides being due to periodic influences, which in themselves are approximately circular in character of function, it is natural to expect that the complete equation of tidal movement for any locality may be expressed in the form of a Fourier's series, of which the constants may be determined by a series of observations on the tides in question.

This analysis has been effected for the tides in several localities, and Lord Kelvin has devised an apparatus for aiding in the determination of these constants.

Once these operations effected for a particular locality, we should then be able, with the aid of a few local observations at the time of trial, to lay down a general equation to the tidal velocity at any point, and for any time during the trial.

Assuming the absence of influences due to special and non-periodic causes, such as heavy winds and storms, it would seem as though the velocity of the tide at the particular locality of the ship

for every moment of the trial might thus be known with fair accuracy.

Once this information in hand, the values may be plotted as ordinates on any convenient base-line, and at any convenient time interval depending on the length of run. Drawing a line through the points thus found, we should have a graphical representation of the tidal velocity at the ship for each instant of the run.

Next with a planimeter we measure the area between the curve and base-line. This area, it is readily seen, is directly proportional to the actual distance through which the tide has set the ship back or ahead during the run. The distance itself will be readily found by applying the proper scale ratios.

This method would therefore take cognizance of the varying tidal velocities which affect the ship throughout the run, and therefore, in principle at least, would be superior to other methods of eliminating the tidal influence.

It is well known that the usual method of continued averages is only correct for specially simple forms of tidal velocity variation with time,—forms which in the actual case are probably wide of the mark, especially at times near high and slack water. At these times, albeit the velocity itself is minimum, its rate of change is maximum; while at half-tide the velocity itself is maximum and its rate of change minimum. At half-tide, therefore, other things being equal, the method of continued averages may be applied with more propriety than at high or slack water. Again, it is true that the shorter the course the less influence the irregular velocity will have. It follows that continued averages, in themselves, are more applicable to a mile course than to one of greater length; and in general, the longer the course the more need of some method which shall take measurably accurate cognizance of the variable tidal velocity.

For a single run between points widely distant—such as, for example, the course in Long Island Sound over which several recent Government cruisers have been tried—some such form of treatment would seem especially appropriate.

Mr. Archibald Denny (reply contributed after the meeting): —Mr. Stratton was in error as to my intention, and was corrected by Mr. McFarland and by Mr. Oldham. Measured-mile trials give the accurate speed of the vessel, but must not be confounded with long-distance trials, which are intended to test the endurance of the engines and boilers, or their capability of maintaining a certain power for 4, 6, 12, or 24 hours. At the bottom of page 5 in my paper I draw particular attention to this.

Practically, measured-mile trials standardize the propeller, and enable a long trial to be carried out independent of a measured basis by the number of revolutions only.

Mr. Raynal is astonished that I recommended starting at the highest speed and going down. We do this because we find it more easy to control a falling steam supply than a rising steam supply, and hence we get more steadiness on the slower runs.

Dr. Elgar's remarks are very much to the point, and almost make it unnecessary for me to reply. It is quite true that it does not necessarily follow that because one ship is faster than another on trial that she shall also be faster at sea. It is undoubtedly true that pitching and rolling tend to decrease the smooth-water speed. Form has undoubtedly much to do with pitching and rolling, but there is another element, stowage of cargo, which has perhaps quite as much, and hence the problem becomes very complicated. None of these considerations, however, detract from the value of smooth-water speed trials as a means of attaining the best sea speed, and the naval architect who is possessed of the greatest mass of trial data will undoubtedly be in the best position to design a steamer having the greatest sea speed.

I also entirely agree with what Professor Durand said; as a matter of fact, we are engaged in a series of experiments in the directions he mentions, and have been so engaged for the last five years.

In regard to Mr. McFarland's remarks as to the "Bancroft's" trials, we have also carried out trials on the principle of time and revolutions, to which I understand him to refer.

COASTING VESSEL OF THE ADRIATIC.

XXXIII.

THE COASTING SAILING-SHIPS OF THE ADRIATIC SEA.

BY SIGNOR RODOLFO POLI,

Naval Architect, Chioggia, Italy.

THE distinguished President of this Division of the International Engineering Congress, Mr. Geo. W. Melville, Engineer-in-Chief of the U. S. Navy, having kindly invited me to take part by sending a memorial on the subject of the special type of coasting sailing ships of the Adriatic, I have the pleasure and honor of responding with the following paper.

The subject cannot be of very great interest to scientific men, because it does not lend itself to a purely scientific treatment; my only purpose is to spread beyond the Atlantic a knowledge of a type of vessel which is most noteworthy on account of the shape of the hull, nautical qualities, system of construction, and arrangement of the sails.

It is a type which is adapted to the requirements of the small local trade, to the peculiarities of the coasts and harbors where it is used, to the class of goods transported; and it has attained its present form after having passed through many successive empirical modifications suggested by experience, and adopted with the purpose of rendering it better adapted to its special service.

Notwithstanding its crude shape, which forms a striking contrast to the latest models of naval architecture, the type not only survives, but is coming more and more into general use. This shows that it serves very well the purpose for which it is intended, or, in other words, that it is a very suc-

cessful design, and as such, no matter how antiquated it may be, will afford to the studious material for investigation and comparison.

Vessels of this particular type are called *trabaccoli*, and according to the latest statistics number at the present time 500, with an aggregate measured tonnage of 20,000. The great majority of them are built at Chioggia, near Venice, and their capacity varies from 25 to 100 tons measurement.

Plate I represents one which I have copied from an actual vessel, choosing a model which conforms as nearly as possible to the original type. The drawings represent the lines of the hull outside of the framework.

The following are the principal measurements over all:

Length between perpendiculars, ...	19.00 metres
Breadth at the load water-line, ...	6.00 "
Draught measured from the upper edge of keel with normal load, ...	2.00 "
Draught measured from the upper edge of keel when vessel is empty, ...	1.00 "
Space occupied by hull, ...	140.40 cu. meters
Displacement, ...	144,060 kilograms
Measured tonnage, ...	50 tons
Weight of hull, ...	42,000 kilograms
" " masts, sails, anchors, etc., . .	8,500 "
Area of midship section, ...	9.78 sq. metres
" " normal load water-plane, ...	92.16 " "
Ratio of length to breadth, ...	3.15
" " hull to circumscribed parallelopipedon, ...	0.59
Ratio of hull to circumscribed cylinder, .	0.75
Ratio of midship section to circumscribed rectangle, ...	0.78
Ratio of normal load water-plane to circumscribed rectangle, ...	0.80

The keel is exactly horizontal, and the midship section is situated at a distance of $\frac{58}{100}$ of the length of the vessel from the stern. From the midship section towards the bow for a distance of one metre the hull is cylindrical.

On the half-breadth plan, the dash- and-dot line shows the

curve of the areas of the various transverse sections or the longitudinal distribution of the displacement, the ordinates being on a scale of 0.05 metre per square metre of section. This curve approaches very closely to a parabola of the third degree, of which the equation, with the origin at the vertex, is

$$x^3 = py.$$

The vertex is at a distance of $\frac{62}{100}$ of the length of the vessel from the stern, and the parameter has such values for the two branches of the curve as will cause the latter to pass through the two ends of the vessel. The vertical distribution of the displacement also follows the law of the parabola of the third degree, and this coincidence shows that the curve was made use of by the constructors in ancient times.

Plate II represents the midship section.

The hull is entirely of oak, except the deck-beam shelves and the deck-beam clamps, two courses of ceilings, and those beams not adjacent to the hatchways, which are all of larch. The deck planking is of pine. The hull is sometimes sheathed with zinc, and the fastenings are of galvanized iron.

The frames, as may be seen in the figure (Plate II), are composed of five pieces, viz., the floor, the futtocks abutting against it, and two bilge-pieces which overlap and bind the futtocks to the floor. In many cases the futtocks overlap the floor, and thus the bilge-pieces are dispensed with. The deck-beams have little depth, but, on the other hand, are very broad, the distance between them being no greater than their breadth. The deck-line is shown in Plate I by a dotted line on the sheer plan.

The method of laying down the hull is very original and ingenious: instead of laying down the lines in the mould loft, a single mould, manipulated in the manner which I am about to explain, serves for laying out the frames on the spot where the vessel is building.

This mould (Plate III) is composed of two parts, *AC* and *BD*, which overlap along the line *BC* common to both. The position of the longitudinal vertical central plane of the ship is shown by the line *o′o*. The contour *AoD*, which is that of the midship section, is formed approximately by three arcs of circles having the same radius, *Aa*, *pp′*, *a′D*, and of two others,

ap and *p'a'*, having their centres at *b* and *b'*, which are the points of intersection of the right lines *pd* with *ac* and of *p'd'* with *a'c'*, on which lie the centres of the arcs before mentioned. The points *p* and *p'* lie at a distance from the middle point *o* which is equal to one fourth of the maximum length of the vessel.

To obtain the contour of the successive transverse sections* the two parts of the mould are brought together, taking care that they always coincide along the common part *pp'*, which is continually diminishing in length. The curve *pp'* being an arc of a circle, the branches *A* and *D* will assume an inclined position, the angle continually increasing as the points *p* and *p'* approach each other. The divisions *o*, IV, VIII... XX on the two parts of the mould show how much those parts must be moved to obtain the curve for any given section; thus, for transverse section No. 8, the marks VIII, which are found on the two parts of the mould, must coincide. In this manner the portion *eaA* of the contour of the section is obtained.

To get the other part, that is, the lower part, another mould $e_1p_1f_1$ with the same curvature as *epf* is used. The point *e* is at the middle of the arc *ap*, and *f* is at a distance of 0.50 metre from *o*. This second mould is made to slide along the first in the direction of the arrow in such a way that the curve e_1p_1 always coincides with the arc *ap*. In proportion as we proceed from the midship section towards the ends of the vessel the points *p* and p_1, which at the midship section coincided, now gradually become more and more distant, and naturally the point f_1 is continually receding from *f*, and thus is obtained that fineness of the lines which is necessary at the bow and stern.

The distance which it is necessary to move the point p_1 from *p* is marked on the mould e_1f_1 by the divisions p_1, 4, 8, 12, 16, 20, which correspond with the transverse sections, that is, the marks p_1, 4, 8, . . . 20 should coincide with *p* to get the contour of the midship section and sections 4, 8, . . . 20. The figure shows the moulds in position for obtaining the curve of section No. 20, which is *Aaeg*. The point *g* lying on division No. XX prolonged, is the middle of the keel.

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* The moulding edges of the frames.—*Translator.*

It often happens that the curve *ap* only slightly approximates to the arc of a circle, and then it is impossible to fulfil the condition that the curve e_1p_1 coincide with *ap* when determining the position of the mould e_1f_1. In that case recourse is had to a small board *EF*, on which are marked by the midship section and divisions 4, 8, . . . 20 the distances at which the point f_1 should lie from the curve *pp′*, that is, the distance from *pp′* of the point where the contour of any given cross-section pierces the central vertical longitudinal plane of the vessel, the other end of the mould being placed tangent to the curve *ap*. The breadth of this board is the same as the breadth of the keel, and it is placed with its middle line on the midship section and marks IV, VIII, . . . XX, which, as I said before, correspond to the position of the longitudinal plane.

This curious method of laying down the curves of the sections, which in practice is very expeditious, serves for all that part of the vessel which, in the case in question, extends from section No. 20 aft to section No. 14 forward. No rule is followed in determining the curve *AoD* of the midship section, nor in laying off on the mould the midship section and divisions 4, 8 . . ., IV, VIII . . ., which in turn determine the contours of the corresponding sections of the fore body and after body. The practical ability of the constructor, in deciding upon a suitable shape for the vessel, is the sole guide which determines the form of these moulds.

But, for the most part, the moulds in use at the present day are very old; ordinarily they form part of the outfit of the yard, and as such are passed along from one proprietor to another and from one constructor to the next, frequently modified or improved by the practical experience of the man who uses them. Generally, three sets of moulds for vessels of 25, 50, 75 tons measurement are made to do for all sizes between 25 and 100 tons, and the constructor adapts them to each special case by suitably adjusting the breadth and depth of the vessel, according to the tonnage he wishes to obtain.

Having settled upon the form of the hull for that part of the length of the vessel already mentioned, the corresponding frames are fixed in place on the keel, and the ribbands attached. The framework at the bow and stern is then completed in a very summary and primitive manner.

The stern and stern-post being fixed in position, the

ribbands of the middle body are prolonged and attached to them, adopting with a practical eye such curves as best suit the particular vessel under construction. For this purpose, battens of wood, curved by steaming, are used; and to insure symmetry of the two sides of the hull, care is taken to cut the two corresponding parts, right and left, of one mould out of the same piece of wood, and to bend them with steam while firmly bound together.

The shapes of the bow and stern being thus fixed, the moulding edges of the remaining frames are determined from them by the ordinary practical methods.

The arrangement of sails adopted is peculiar to this particular type of vessel. There are two vertical masts (Plate IV) with trapezoidal sails, and a movable bowsprit, which may be unshipped and rigged on the foremast. A single jib is carried, but three different sizes of jibs are provided, and the particular size to be used at any time is regulated by the number of reefs in the other sails.

The point of attachment of the jib to the bowsprit is variable, and by a system of pulleys may be drawn in toward the vessel or moved further away, thus allowing the sails to be balanced in a very convenient manner.

The position of the masts is determined about as follows: The length of the vessel between perpendiculars is divided into nineteen parts, and the mainmast is placed at the fifth division, counting from the stern, and the foremast at the fifteenth division. The length of the foremast from "heel to hounds" is three times the beam of the vessel, and the mainmast is 0.50 metre shorter.

The total sail area is 327.50 square metres, and is proportioned as follows:

Ratio to midship section,	33.48
" " load water-plane,	3.55
" " displacement,	2.27
" " (displacement)$^{\frac{2}{3}}$,	11.90

The sail area is divided up as follows:

Mainsail,	140.00	square metres
Foresail,	146.00	"
Jib,	41.50	"

The "centre of effort" of the sails is situated at the height of 9.52 metres above the load water-plane, and 0.10 metre abaft the perpendicular line passing through the middle point of the vessel's length.

The "centre of effort" of the sails is 0.75 metre (about $\frac{1}{18}$ of the vessel's length) forward of the "centre of lateral resistance," the measurement being taken on a horizontal line.

Plate V shows the "metacentric curve." Curve No. 1 is the locus of the "centre of buoyancy," No. 2 the locus of "transverse metacentres," No. 3 that of the "longitudinal metacentres," No. 4 the "curve of displacement," No. 5 the curve showing the stowage capacity of the hold, No. 6 the locus of the "centres of gravity" of that space.

All the quantities are on a scale of $\frac{1}{50}$, except the ordinates of curve No. 3, which, measured from curve No. 1 (radii of "longitudinal metacentres"), are on a scale of $\frac{1}{250}$, and the abscissæ of curves Nos. 4 and 5, which are one, on the scale of one centimetre per ton, and the other one centimetre per cubic metre.

The normal load water-plane is that shown in Plate I. L_1 corresponds to the conditions when the vessel is empty, when, as I said before, its displacement is 50,500 kilogrammes; C_1 and M_1 are the "centre of buoyancy," and the corresponding metacentre; G_1 the centre of gravity, which I have found by experiment. The metacentric height $G_1 M_1$ is 1.40 metres.

To determine the conditions of stability of the vessel when loaded, I have chosen two extreme cases, viz., the lightest and the heaviest cargoes usually transported by these vessels. These are firewood and boards, and building-stone (carbonate of lime), which indeed constitute the cargoes of these vessels to the exclusion of almost everything else.

In the case of the cargo of wood, the vessel is loaded down to the line L_2 and displaces 150,000 kilos. To render the vessel seaworthy 12,000 kilos of ballast are carried, leaving for the cargo 87,500 kilos, which occupy a space of 175 cubic metres. The available space in the hold being 109 cubic metres, the balance, 66 cubic meters, weighing 33,000 kilos, is placed on deck. Under these conditions, the centre of gravity is at the point G_2, and the metacentric height $G_2 M_2$ is 0.89 metres.

In case the cargo is building-stone the vessel is loaded

down to the line L_3, corresponding to a displacement of 160,000 kilograms. It is customary to place in the bottom of the hold a layer of boards to act as a cushion to prevent the cargo which is dropped down the hatches from striking and injuring the bottom of the vessel. These boards weigh 6000 kilos, leaving 103,500 available for the cargo, two-thirds of which is stowed in the hold and one-third on deck, under which conditions the centre of gravity of the vessel is at the point G_3, and the metacentric height $G_3 M_3$ is 1.04 metres.

Plate VI shows the curves of stability for the three cases which have been considered, viz.:

Curve No. 1,	displacement	50,500	kilos,	GM	$= 1.40$
" " 2	"	150,000	"	"	$= .89$
" " 3	"	160,000	"	"	$= 1.04$

Curves Nos. 1, 2, and 3 show the lever-arms of stability, while the corresponding Curves I, II, III show the moments of static stability. As may be seen, the stability becomes zero when the vessel is empty and inclined at an angle 62° 6′, when loaded with wood and inclined 46° 48′, loaded with stone and inclined 54° 18′.

The "dynamic stability" which is represented by the areas of the curves has the following relative values: Curve No. I 0.78, Curve No. II 0.75, Curve No. III 1.00; and these values denote the relative degrees in which each of the before-mentioned conditions is favorable to the stability.

In order to investigate the stability under sail I have drawn the curve S of moments of the force acting on the sails, assuming the pressure of the wind to be 4.8 kilos per square metre, which is, under normal conditions, the pressure of the wind when all sail is made. It is not necessary to add—because the diagram shows it very clearly—that the vessel is found to be in excellent condition with regard to stability, in each of the three cases under consideration.

Passing on now to the examination of the other nautical qualities of the vessel, it is found by experience that, with regard to rolling in a seaway, the period of oscillation is a good one when the lighter load (Case No. 2) is carried. Naturally with the heavier load (Case No. 3) the great metacentric height renders the oscillations more frequent and the rolling more trying. To obviate this inconvenience it has been the custom, handed down from ancient times, to "wing out"

all the weights on deck; and this proves that the knowledge of the influence of the moment of inertia of the vessel on its rolling qualities is very old.

The amplitude of the oscillations is not great. The low free-board allows the decks to be awash at a very slight angle of heel, augmenting the resistance of the water and tending to reduce the angle.

The vessels are defective with respect to the "dipping oscillations" due to the peculiar form of the transverse sections. But these movements do not attain any great amplitude, and therefore the defect is not of much importance. The "longitudinal oscillations" (pitching and scending—*Translator*) are not very pronounced on account of the fulness of the lines at the bow and stern, especially at the bow.

With regard to the speed, these vessels utilize the propulsive force of the wind very well for moderate speeds. Up to a speed of six knots per hour the frictional resistance is about the whole resistance offered by the water; and these vessels, other things being equal, will make greater speed than those having finer lines, both because the wetted surface is less and because the greater stability allows more sail to be carried. Beyond the limit mentioned the propulsive force of the wind is almost all lost in the formation of waves, which reach a great size on account of the excessive fulness of the bow.

The arrangement of the sails has the advantage of being simple and therefore cheap, and only a small crew is required to handle them. The shape of the sails is adapted for sailing "on the wind" as well as "before the wind," and possesses the advantages both of fore-and-aft and square rig.

The shape of the rudder is worthy of special attention. It is extended below the keel with the manifest purpose of rendering it more efficient (on account of working in still water), easier to move, and for the purpose of increasing the resistance of the vessel to rolling.

It is true that in certain cases this projection of the rudder below the keel might seriously endanger it; therefore the pintles are made as shown in the drawing, so that by means of a tackle the rudder may be hoisted to the level of the keel when necessary.

After what has been said, it will not be denied that the type is a good one for *sailing-vessels* of *small tonnage;* and its

adoption, which is becoming more and more general notwithstanding the antiquated form, which recalls the late vessels of the Venetian Republic, is justified by the low first cost and good nautical qualities. Indeed, the small draught, good manœuvring qualities, stability under a wide range of conditions, facility with which it may be "careened" for repairs to the hull, ability to sail empty without ballast, moderate rolling and pitching, fair speed, comparatively large cargo carried, and cheapness on account of the simplicity of the system of construction and arrangement of sails, form such an aggregate of good qualities that the sailors of the Adriatic prefer it to the modern types of the most graceful and elegant models.

Moreover, it must be borne in mind that the traffic of these small sailing-vessels is not very remunerative: the owners are for the most part poor men who, in order to purchase the boats, have not only spent all their own money, but have even contracted a debt, and to render the business lucrative they are obliged daily to expose the lives of themselves and all their sons to the perils of the sea.

It is natural, therefore, that in the construction of these vessels economical considerations should prevail, that is, the attempt is made to get a good sailing-vessel at the least possible price. The type in question fulfils both these conditions in a very satisfactory manner.

In concluding this monograph in which I have been more diffuse than the subject justifies, I desire to express the wish that I may be followed by others in this same line of research. Every sea, it may be said, has special types of coasting and fishing vessels, which represent a certain quantity of practical experience and a series of empirical trials, of greater or less length, made for the purpose of adapting the vessels to the service for which they are designed. They are types which, for the purpose for which they are intended, attain a certain degree of perfection, but which for other uses would have to be modified or replaced by a different type, better suited and more perfect for the new service. A collection of data relating to these vessels, so numerous and so varied in form, could not fail to be of advantage to the progress of science, and would pave the way for theory where now empiricism reigns supreme.

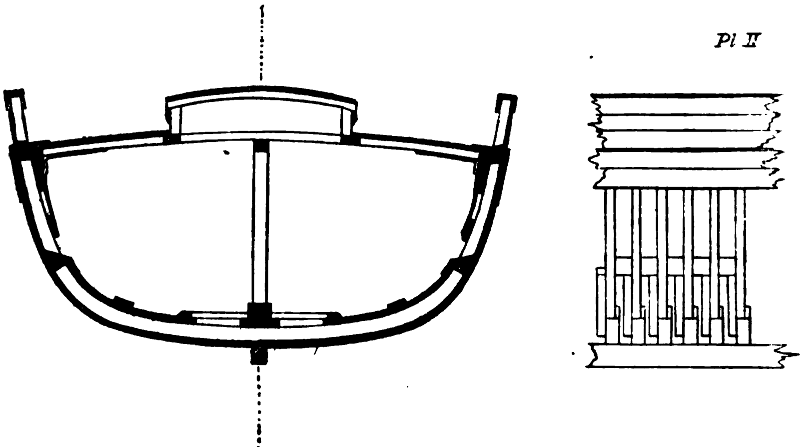
One of the most important problems of naval architecture

which has not yet been solved is that of the arrangement of the sails, that is to say, the determination of the best position of the centre of effort of the sails for a given vessel. The position of this point, which has such immediate connection with the speed of the vessel and her manœuvring qualities, is at present governed by empirical rules; and whenever the naval architect has no model of a similar vessel to copy from, he is very much perplexed, and runs the risk of being obliged to make radical changes after the vessel has been tried at sea. To obtain a general solution of the problem which would be sufficient, at least, for all practical purposes, it would be necessary to obtain a large and varied quantity of data relating to vessels of good design, and for this purpose it seems to me that there could not be any better material than that furnished by the various types of coasting and fishing vessels of different seas. They would supply variety of form, stability, arrangement of sails, and many other elements, and their designs would be the result of long-continued and extensive experiments.

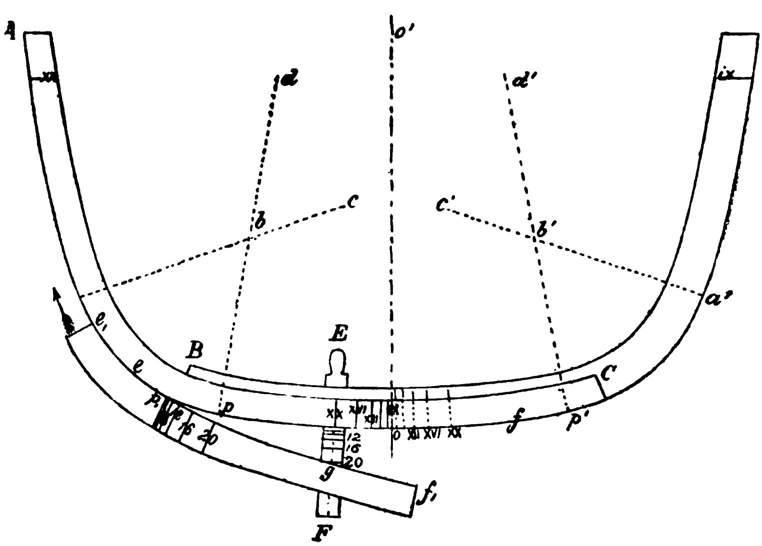
Referring now to the type discussed in this paper, the coasting sailing-vessels of the Adriatic number, as we said before, 500, and they all resemble each other very closely with regard to stability, position of the centre of effort of the sails, and in every other important particular. How much a change in the ordinary arrangement of the sails can injure the nautical qualities of the vessel is frequently shown when attempts are made to deviate from the usual practice. There are, then, 500 vessels which attest to the fact that the present position of the centre of effort of their sails is better than any other, whatsoever it might be, and which constitute an unquestionable proof that the arrangement of the sails is a good one and therefore afford an excellent subject for study. What I have said of this type may hold good with regard to other types in other seas, and I argue, therefore, that the data furnished by these vessels would be the very best, because relating to successful designs and because they would embrace such a great variety of types.

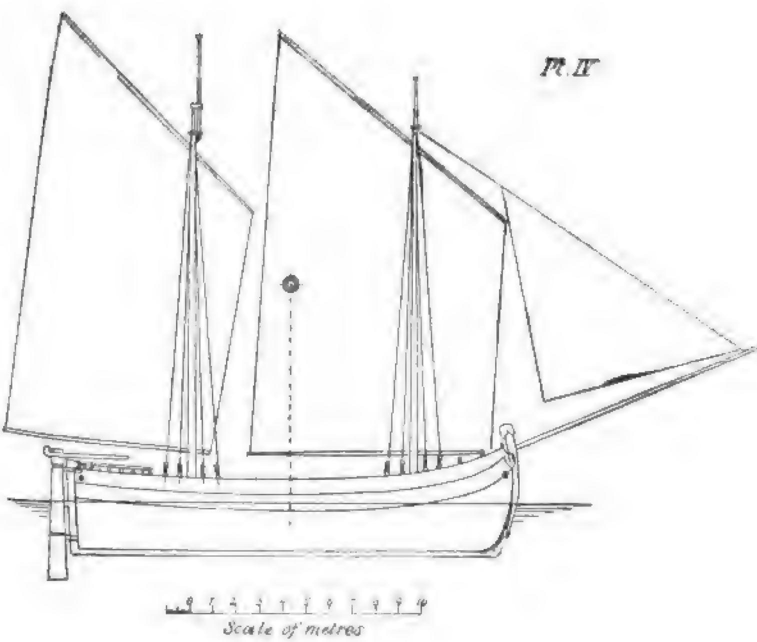
Such is the wish which I submit to the wisdom and judgment of the Congress.

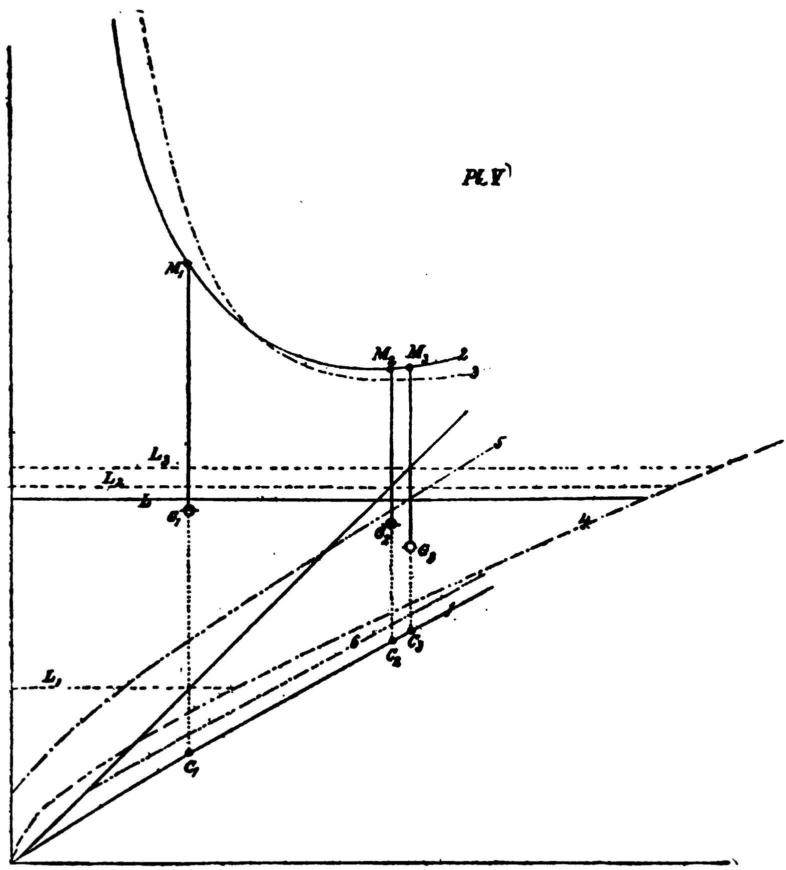
Pl II

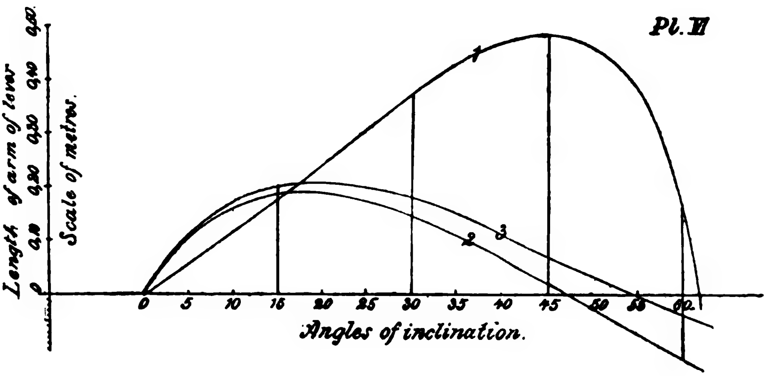


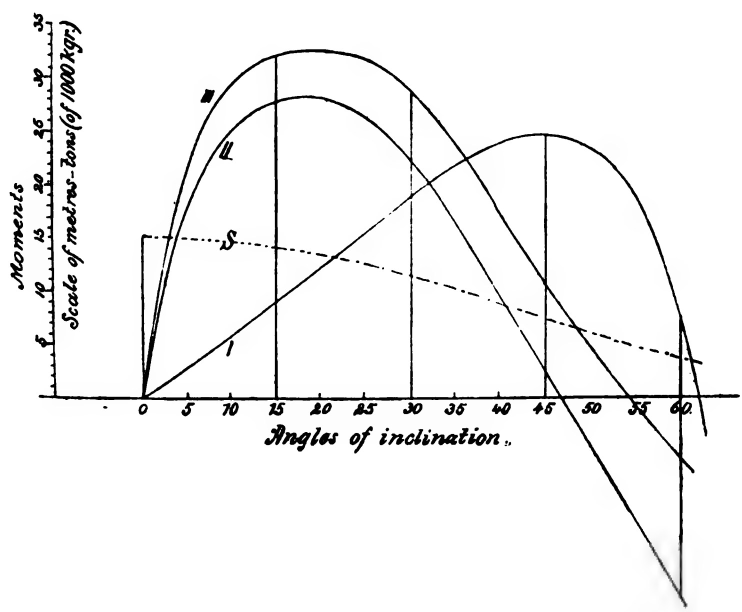
Pl. III




Pl. IV
Scale of metres




Pl. VI
Length of arm of lever
Scale of metres.
Angles of inclination.


Moments
Scale of metres-tons (of 1000 kgr.)
Angles of inclination.

XXXIV.

STEEL CASTINGS AS USED IN MARINE MACHINERY.

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Having had the honor to be invited by Engineer-in-Chief Geo. W. Melville, U. S. N., Chairman of the Naval Division of the World's Engineering Congress, to offer some observations on "Steel Castings as used in Marine Machinery; their Successes, Failures, etc.," I will endeavor to present in the simplest and tersest form the results of my experience and observation.

The past twenty years has been a period of phenomenal development in all branches of naval architecture and marine engineering. Constantly increasing demands for greater speed, comfort and safety in passenger traffic, greater economy and lower rates of insurance in freightage, together with the palpable revolution that has taken place in man-of-war construction, equipment, armament, and power, have all combined to force inventive genius and mechanical skill to their ultimate energies.

From the beginning of the steam era, castings have been an important factor. In the earlier days there were a few attempts on a small scale to make wrought-iron built-up bed-plates and frames, but they were not generally successful; so that cast-iron soon became the standard and exclusive material for bed-plates, frames, cylinders, pistons, pedestals, and in fact all the massive factors of marine engines.

Cast-iron, with its natural and necessary limitations, was and remains a reliable metal: rigid where stiffness is required, as in bed-plates, frames, etc.; hard where good working surface is needed, as in cylinders, valve-chests, eccentrics, etc.; and, generally speaking, faithful and efficient for long and hard

service when properly made and of sufficient sectional dimensions. Moreover, it is dense, homogeneous, free from blowholes, honeycombs, and other defects calculated to produce weakness or leakage when worked under pressures of steam or other fluids, and by virtue of all these qualities it presented a wide range of utility in marine engineering.

But, in order to secure the best results from cast-iron, it was necessary to be liberal in the element of massiveness, which of course entailed weight; wherefore, the imperative demand of recent years for the development of increased power on given engine weight, forced engineers to the quest of other metals.

Prior to the discoveries of Sir Henry Bessemer and the improvements of Dr. Siemens and Mr. Martin, all steel castings were made from crucibles; and while these were in many directions successful, and even comparatively economical on a small scale, it was never found practicable to assemble crucible charges in the massive castings required for large marine engines.

Some attempts were made abroad, before the advent of the open-hearth system, to make massive steel castings by melting in the cupola furnace used for casting iron, but they were unsuccessful in consequence of the higher temperature required for free flow, and for other well-known reasons, and were therefore abandoned.

The evolution of the open-hearth furnace solves some aspects of the problem, but not all, and many of its elements yet remain to be perfected. On any large scale for heavy engine-work, the use of steel castings was inaugurated in Great Britain. Many years ago crucible cast steel was used for spur-wheels, millwright work, and small details of locomotive and stationary engines.

Propeller blades were cast of steel, and used largely and successfully as early as 1870. Mild-steel castings came into use with the Siemens-Martin open-hearth process over twenty years ago, and the founders succeeded in making steel castings of much greater strength than cast-iron, very ductile, and capable of being welded. The material gave promise of supplanting forgings for many uses, and of replacing iron castings by reason of great reduction in weight. The British Admiralty, specially desiring to reduce the weight of machinery car-

ried in the ships of the navy, encouraged its use. The first attempts showed that, while patterns of simple form and not too thin section could be made quite successfully, complicated pieces required much care and skill to avoid tearing and unsoundness, which might develop partly from the great shrinkage in cooling in the hard unyielding mould, and partly from the evolution of gases after the metal had been poured, so that, at first, it was difficult to get these castings quite solid and the surfaces were always rough.

Dr. Kirk, of Napier's, looking to the reduction of the weight of moving parts in high-speed engines and the resulting decrease of the inertia strains, found in the piston a suitable subject for cast steel, and designed his large pistons of one single conical sheet of steel. In conjunction with the West of Scotland Steel Co., he succeeded, after much patient experiment and many failures, in getting reliable, light, and strong pistons. About 1880, the first of these was made for H. M. S. "Leander," and they have been adopted for nearly all war ships and in most first-class merchant ships built since that time.

In 1882, turning gear-wheels were added to the list, and though strong were very rough. Reversing-levers, being of simple forms, were also cast quite successfully, no machining being required beyond boring and facing.

In 1883, with the introduction of radial valve-gears, came more complicated quadrants, with right-angle arms and trunnions. These quadrants and levers would have been heavy in cast-iron, and expensive in bronze or forged steel; wherefore cast-steel did much to render these gears commercial possibilities. The only machining required was that of the slide, faces and trunnions, and these proved quite sound, and free from blow-holes and flaws. Cylinder-frames and rams for hydraulic flanging-presses and riveters were found light and sound. Thrust-block shoes and eccentric-straps formed simple and reliable castings. In ships, particularly men-of-war, the stern-posts, rudder framing, ram bows, and the A-frames or struts of twin screws, huge steel castings of simple sections, were made with entire success.

About 1886, engine-framing was attempted. After many failures and mishaps comparative success was obtained. Accidents such as that to the engine-framing of one of H. M.

cruisers gave warning of the necessity of careful management in the foundry and of careful testing of the castings. The break showed quite sound metal, but coarsely crystalline, more like cold-blast cast-iron than steel, probably due to lack of thoroughness or improper management of the annealing process.

In designing steel castings, continuity of section was aimed at and right-angled ribbing avoided, since it was found that a line of weakness extended along the junction of such intersecting planes. When flanges were used, little triangular brackets were inserted at short intervals as feeders for the metal, and to help to tie the right-angled planes during cooling. These brackets were removed after performing their office.

Early in 1888, bed-plates were treated on these lines, and subjected to a drop test satisfactorily. To avoid straining during cooling, steel bed-plates were built up in straight pieces, the crank-pit being surrounded by two cross main-bearings and two longitudinal side frames. In some gunboats, the frames were of cast steel, similar to sketch A; but the tie-rods from the cylinders to frame tops carrying valve-gear bearings were I-section castings, very light ($\frac{3}{4}''$ thick); and excellent castings of that small size were obtained. They were tested to twice the working strain for tension in a testing-machine and in other ways, and have stood all right in the engines. About this time, cast-steel was employed for hubs of propellers, but these were not much lighter than cast-iron. Steel framing for vertical engines was also made successfully of very light I-section for battle ships. In merchant work about this time, the engine-framing of some ocean liners was designed similar to the ordinary cast-iron box-section split column, with cross-ribs inside. These were not entirely successful, steel refusing to behave quite like cast-iron and demanding a form more suitable for the material, in consequence of the flow of molten steel being less "free" than iron.

In 1890, in the effort to get over the risks of cast-steel in the split columns of engine-framing, they were cast in two vertical sections, open on one side, and then bolted together, thus simplifying each casting and reducing the difficulties.

In the "Maine" of the United States Navy, and in some cruisers of the British Navy, of similar type, the framing was

of wrought-steel, except the bed-plates, which were ribbed castings of I-section. For some cruisers built at this time for the British Navy, cast-steel was used for receiver-pipes, safety and stop valves, double-beat valves, and cylinder-covers, bends, and separators. More than one contractor for the latest first-class cruisers of the British Navy has preferred to make columns and bed-plates of cast-steel in the form of a heavy solid slab. In this form the result was a perfectly sound casting, of good soft steel, and fitted well into the ships' structure.

In the earlier years of mild-steel castings, about one sound casting was obtained out of four or five delivered to the machine-shop, but of late about 20% or 25% only have been rejected after machining and testing; the risk depending on the thickness of section, simplicity of form, and dimensions of the casting. With large thick masses, such as propeller blades, or the slab beds for marine engines, there was no difficulty at all. The test-pieces stood well in tension and bending, and the surface machined quite solid.

In pistons with big hubs at centre, and a web growing thinner towards the rim, which is again heavy, the risk is greater, a tendency existing to crack round the flange, or radially at the flange edge. Sometimes a crack would show on the body, of small extent. The founders preferred to put cores through all bolt-holes in hubs, so as to reduce the mass, and equalize the cooling and shrinkage. In some cases it was asked that these pistons should be machined all over, and this was done successfully in about 60% to 70% of the attempts. These pistons were subjected to cold-water hydraulic test of twice the working pressure, as well as to tensile bending and temper tests of pieces from them.

Hydraulic cylinders and rams turned out solid without trouble, being simple forms of moderate size, and not too thin for the flow of viscous material. Radial gear quadrants were more troublesome because of the right-angled intersections of thick and thin masses at the trunnions. These trunnions were sometimes cored out as much as possible, and, after a little experience, about 60% to 75% could be relied upon to come out of the machine solid. The trouble generally occurred at the junction of the trunnion with the quadrant, where "honey-

combing" or "blow-holes" formed. The working faces were usually solid.

Cylinder-covers of large size (40″–59″–88″) for H. M. first-class cruisers were cast with single webs ribbed as shown on the accompanying sketch. These castings were complicated, and caused much trouble in the foundry, and in the machine-shop also. The bending and stretching tests did not come up to requirements, the material having been necessarily made hard so as to give fluidity enough for casting in such complicated patterns. The larger of these castings twisted or warped somewhat, and a silicious skin or envelope from the mould adhered to the flange-faces. It was so hard that no ordinary tool could touch it, and special steel was got to remove it laboriously by a slow scraping process. The castings were very rough also. They were sound, however, and though costing a good deal to machine them, seemed fit for their work. Later experience enabled the founders to produce these cover castings free from the defects above enumerated.

Steel pipes and bends were also adopted with a view to getting a solid, reliable steam-pipe of large size. After the many serious accidents to large copper steam-pipes due to the brazed joint giving way, solid-drawn, wire-wound or clasped copper pipe, or wrought-steel pipes were resorted to for the straight lengths. The bends, branch and Y-pipes, and stuffing-boxes seemed more conveniently made of cast material; and the choice lay between brass and steel, since cast-iron would be too thick and heavy for war-ship practice, and even for passenger liners. The material being very much stronger than any of the bronzes, gave encouragement to a trial on valves for steam purposes also. And, further, since the boiler is of steel, the engine-cylinders, valve-casings, and valves of cast-iron, liners, and pistons of steel, it seemed a rational proceeding to connect these if possible by an iron or steel communication, and so avoid to a large extent questions of electrical or galvanic action. If, with this advantage, the cost could be materially lessened, then it seemed wise to encourage the steel-founder to try his best on such pieces. Very few castings were thrown out. The surfaces of these castings are a little rougher than cast-iron, but a great improvement on castings of former years, and quite presentable. As to the thickness of smaller castings of good mild ductile material,

which were obtained from the steel foundry, the following were noteworthy:

24″ pipe, $\frac{7}{8}$″ to 1″;
19$\frac{1}{2}$″ pipe, $\frac{7}{8}$″;
10″ pipe, $\frac{3}{4}$″;
6″ pipe, $\frac{5}{8}$″;
14″ double-beat valve, $\frac{\,}{8}$″.

These could all be cast thinner of a harder steel, but the Admiralty tests in elongation and bending had to be complied with. At these thicknesses, an 18″ cast-steel steam-pipe is rather over twice the weight, four times the strength, and about one half the cost of a copper pipe of same size. The difference in favor of steel castings for pipes and valves is greatest at the larger sizes, and disappears when pipes and valves are from 4″ to 6″ in diameter. The tests demanded for steel castings by the British Admiralty were, in March, 1888, tensile strength 28 to 32 tons, and in 8″ test-pieces 10 per cent elongation; piece 1″ square to bend through 90 degrees angle over 1$\frac{5}{8}$″ radius.

In 1890 they were as follows:

"All steel castings are to satisfy the following conditions: Tensile strength not less than 28 tons per square inch with extension, in 2″ of length, of at least 13$\frac{1}{2}$ per cent. Bars of the same metal 1″ square should be capable of bending solid without fracture over a radius not greater than 1$\frac{5}{8}$″ through an angle depending on the ultimate tensile strength. This angle to be not less than 90 degrees at 28 tons ultimate strength and not less than 60 degrees at 35 tons ultimate strength, and in proportion for strength between these limits. Test-pieces to be taken from each independent ingot and casting."

Though the Siemens and Siemens-Martin processes of casting direct from the furnace, that is to say, from the original charge of converted metal, produced results largely in advance of anything that had been achieved by the crucible system, much was still left to be desired. The direct castings were at best nothing but raw-steel ingots, and differed from common working ingots only in the fact that they were moulded to patterns. They almost invariably showed blow-holes and hard spots or lumps, due

to segregation of impurities, which not only impaired the soundness of the metal, but gave great trouble to the machinists by breaking their tools or otherwise impeding the work.

Relief from these difficulties was found a few years later in improved methods of French origin, commonly known as the Terre-Noir process, which, with various modifications, now forms the basis of all furnaced steel castings.

This process did not, indeed, wholly do away with the blow-holes, which are still found in castings under the most approved processes, nor did it entirely obviate the tendency to segregation; but it reduced both, and altered the situation to the extent of making sound castings—in practicable patterns, of course—the rule and defective ones the exception, whereas under the former systems the reverse had been true.

This survey of the history of steel-casting development abroad seems requisite to a proper understanding of the results that have been achieved in the United States, and an adequate apprehension of the conditions under which the industry was inaugurated.

STEEL CASTINGS IN THE UNITED STATES.

The use of steel castings in this country on a large scale for marine work, both in engineering and construction, began with the adoption, by Secretary Whitney, of the plans on which the earlier ships of his administration were built. This group included the "Newark," "Charleston," and "Baltimore," cruisers; "Yorktown" and "Petrel," gunboats; and the "Vesuvius," dynamite gun-vessel; and active operations upon them were begun in the latter part of 1886.

The initial efforts were not made by very easy stages of development. On the contrary, the steel-founders of the United States, when they undertook to execute the work called for by these plans, passed at once from a state of almost total inexperience to the production of the most massive and intricate patterns known to the trade.

About all that was definitely known was that similar castings in steel had been produced elsewhere with more or less success, but details were wanting. The French and

English founders who had brought the art to its then state were reticent both as to their processes and as to the percentage which their successes bore to their total of effort.

The results of the earlier operations of our founders were not encouraging. In the case of the "Baltimore," as many as twelve castings were made to produce three pistons. However, the manufacturers persevered. On the other hand, designers, both in the Navy Department and in private shipyards, rapidly acquainted themselves with the peculiarities of steel, and tried to meet the founders half-way by simplification of patterns and adaptation of shapes and sections to the characteristics of the metal.

Still, there was a good deal more theory than practice on both sides, and it early became evident that the steel-casting problem afforded a very wide field for practical investigation, experiment, and skill.

It was soon found that a hard steel would pour freer than a soft one, and would also cool with less violent contraction or shrinkage, but then it would not stand the stretching and bending tests required. It was stronger than cast-iron, but not much tougher, and hence could not be trusted to do important work on much less massive section.

On the other hand, the soft steel which would stand the tests would not pour well, and in cooling in intricate patterns or large disks it would crack or warp from the rapidity and extent of its shrinkage. Escape from one horn of this dilemma for a time seemed to unavoidably land one on the point of the other horn.

Designs of bed-plates, columns, frames, pistons, stems, stern-posts, shaft-struts, stern-tubes, and other large masses were modified from time to time as experience developed the impracticability or great difficulty of original devices, until finally a tolerably fair basis of compromise was reached about 1890–91. The experience of the Navy Department during this epoch is vigorously described in the report of Engineer-in-Chief Melville, covering the operations of the year 1890. He says:

"I am again obliged to report that we are having most discouraging experience with steel castings, and that the statements in former reports concerning them can be repeated almost without change, for in some cases parts de-

signed of cast-steel have been "built up" of forged or rolled steel; in others the castings have been reinforced with plates of rolled steel; and in still others the castings have been made abnormally heavy, and reduced to size in the shaper or planing-machine.

"The publication of these reports has evidently directed considerable attention to this matter, and has elicited letters to the technical press from representatives of several of the steel-casting establishments. Without exception they admit that there have been many failures and delays, but they endeavor to escape the charge of poor work for the Government by stating that they have done better work for other parties, and by claiming that the designs for machinery call for shapes that cannot be succcessfully cast in steel; they also imply that if the steel-makers were allowed to modify designs and split one casting up into as many as they choose they could guarantee good work. One writer goes so far as to state that they do not claim any reduction of weight from the substitution of steel for iron, but that the parts will be so much stronger that there will be much less danger of a break-down.

"Whatever truth there may be in the charge that some designers ask for shapes that cannot be cast successfully in steel, it does not apply to the designs for the machinery of our new ships, for, without exception, the steel-makers have been met in friendly spirit by the Bureau, and every change which they have suggested within reason has been allowed. But there must, of course, be a limit to this: we do not design machinery for amusement, nor to ascertain if steel-makers can cast the parts, but to answer certain very definite purposes. If cast steel will fill the requirements better than any other metal, we desire to use it; but if we are to be hampered by being limited to a few shapes, and having pieces which would be one easy casting in iron cut up into a number involving expensive machine-work to fit together, and the uncertainty of bolted joints in the very places where simplicity and solidity are most needed, then the conclusion cannot be avoided that steel castings are not desirable for such purposes.

"It is interesting to compare the attitude now taken by the steel-makers with that assumed by them some seven or eight years since, when the first of our new vessels were

building. They claimed then that they could cast anything in steel that could be cast in iron, and the Advisory Board (which was then responsible for the general designs of the ships and machinery) was criticised for its unwillingness to accept these statements without question and use steel castings for all parts of machinery. When it was found that a fair degree of success had been attained in steel casting, they were taken at their word and given opportunity to show their capacity, and now they claim that the shapes called for (which are neither intricate nor new) cannot be cast.

"It cannot be too plainly stated or strongly emphasized, that the only reason for using cast-steel instead of cast-iron is that advantage may be taken of its greater strength to reduce weights. There can be no greater absurdity than to make steel castings of the same size as those of cast-iron with a view to greater safety if the strength of the iron casting is ample; steel castings cost four or five times as much as iron ones, and it would be a deliberate waste of public money to use material in this way. The same is true of the plan of making pieces of several parts bolted together.

"The little progress made in the production of steel castings was proved in a marked degree with the engine columns of a certain ship. These were perfectly plain hollow columns, and in cast-iron would have been the simplest kind of work; in cast-steel every one was so imperfect that they could not be used. After the failure of these columns the steel-makers claimed that they were of a shape impossible to cast in steel, but before the castings were found defective not one of the makers thought there would be the least trouble in making them."

The Engineer-in-Chief displays his characteristic vigor of diction in this part of his report, and it is possible that he has left no word of needful censure unsaid. The incertitude of the steel-founders and their wide diversities of opinion among themselves as to what shapes were practicable and what were not, certainly exposed them to the suspicion that they had at that time by no means mastered their art, and that their experience to that date had taught them but few lessons of great or enduring value.

And yet, at the date of the Engineer-in-Chief's observations quoted, 1890–91, American steel-founders had success-

fully produced a considerable variety of heavy and difficult castings, of which the following are the most noteworthy specimens:

Bed-plates up to 24,000 lbs.
Stern-posts up to 54,000 lbs.
Stems up to 21,000 lbs.
Hydraulic cylinders up to 11,000 lbs.
Shaft-struts up to 32,000 lbs.
Hawse-pipes up to 7500 lbs.
Stern-pipes up to 8000 lbs.
Bitts.
Box-housings.
Worm-wheels.
Pistons up to 94" and 7500 lbs.
Eccentrics, etc.

The percentage of success in these classes of castings since 1890 has ranged from 65% in the more difficult forms to 90% in the simpler ones; the tensile strength has been from 62,000 to 78,000 lbs., elongation from 15% to 25%. The best performance recorded is that of a guide, cast in January, 1893, which developed 84,000 lbs. tensile strength and 15.6% elongation.

It should also be borne in mind, in estimating the merit of these achievements, that the castings which our steel-founders struggled with during the period under discussion were turned out under the most searching schedule of requirements and the most crucial system of tests ever imposed on manufacturers of that class of material. I offer a sample of these requirements and methods of test, as approved by Secretary Tracy, May 24, 1889:

STEEL CASTINGS.

100. **Kind of Material.**—Steel for castings must be made by either the open-hearth or the crucible process, and must not show more than six hundredths (.06) of one (1) per centum of phosphorus.

101. **Treatment.**—All castings must be annealed, unless otherwise directed.

102. Sound test-pieces shall be taken in sufficient numbers to thoroughly exhibit the character of the metal in the entire piece from each of the following castings, viz.: Stem, stern-frame, rudder-frame, shaft struts or brackets, torpedo-tubes, hawse-pipes, main-cylinder and valve-chest liners, main pistons and followers, cross-heads, bed-plates and columns of main engine, main valve-stem cross-heads and air-pump columns.

103. All other castings may be tested by lots as follows: A lot shall consist of all castings from the same heat annealed at the same time. From each lot two tensile and one bending specimen shall be taken, and the lot shall be passed or rejected on the results shown by these specimens.

104. The specimens may, at the discretion of the inspector, be cut either from coupons to be moulded and cast on to some portion of the casting, or from sinking heads, in cases where such heads of sufficient size are employed. Coupons to be so fixed as not to interfere with the successful making of the casting, but at the same time showing the average quality of the material. In the case of castings tested by lots, the test-pieces may be taken from the body of a casting from the lot, if so desired by the manufacturer.

105. **Tensile Test.**—The tensile strength of steel castings shall be at least 60,000 lbs., with an elongation of at least 15 per centum in eight (8) inches for all castings for moving parts of the machinery, and at least 10 per centum in eight (8) inches for other castings.

106. The tensile strength of any single casting will be considered satisfactory, provided it shows a tensile strength of at least 60,000 lbs. and the required elongation.

107. **Bending Test.**—Bars of the same metal, one (1) inch square, shall be capable of bending cold, without fracture, through an angle of 90°, over a radius not greater than one and a half ($1\frac{1}{2}$) inches.

108. **Percussive Test.**—A percussive test may be substituted for the tensile test in the case of small or unimportant castings by selecting one casting from a lot for the test specimen of the lot. The lots should be grouped by melting-heats and annealing-furnace charges. All castings must be of uniform quality, free from brittleness or other injurious defects. In the case of the stem, stern-post, and shaft-bracket, and other

large castings, the castings are to be raised to an angle of 60° from the horizontal, and allowed to fall on ground of the same hardness as a good macadamized road.

109. **Surface Inspection.**—After the percussive tests, the stem, stern-post, shaft-brackets, and other large castings are to be suspended in chains and hammered all over with a heavy sledge-hammer and examined for any defect or flaw. All castings must be sound, free from injurious roughness, sponginess, pitting, shrinkage or other cracks, cavities, etc.

110. In case the results obtained from the first submission of a casting do not conform to the specifications, the Steel-inspection Board, if deemed advisable, may permit the manufacturer to re-treat the casting and submit additional specimens, and the results obtained from the former specimens will no longer be considered. Unless otherwise directed, the final process must be an annealing one.

111. At the request of the manufacturer, the Steel-inspection Board may permit the two-inch tensile specimen to be used in testing castings, in which case 5 per centum will be added to the elongation, so that paragraph 105 will read 15 per centum in two (2) inches, instead of "10 per centum in eight (8) inches," and 20 per centum in two (2) inches, instead of "15 per centum in eight (8) inches."

Comparison of these requirements and test methods with those of the British Admiralty, already quoted as for the year 1890, is instructive.

Among the most successful steel foundries in the East, is the Midvale Steel Company, Charles J. Harrah, President and General Manager, Philadelphia. These works are in succession to the old William Butcher Steel Works, which in their day were among the most important crucible-steel works in the United States. The plan of this paper contemplates its embellishment with all attainable experience of the principal steel-founders, and the President of Midvale, in response to my request, offers an interesting and valuable summary of the operations of his company, as follows:

"The first steel castings of which anything is generally known were crossing-frogs made for the Philadelphia & Reading R. R. in July, 1867, by the William Butcher Steel Works,

now the Midvale Steel Co. The moulds were made of a mixture of ground fire-brick, black-lead crucible-pots ground fine, and fire-clay, and washed with a black-lead wash. The steel used was, of course, melted in crucibles, and was about as hard as tool steel. The surface of these castings was very smooth, but the interior was very much honeycombed; as it was not necessary that such castings should be free from blow-holes, but only strong and hard, they answered every purpose, and some made in those early days are still in use. This was before the days when the use of silicon was known for solidifying steel, and, as it was impossible to get more than the lower face solid, the use of steel castings was very limited. One solid face admitted of their use for hammer dies; but the sponginess, which was almost universal, was a great obstacle to their general adoption. On April 28, 1876, two small dies were made of open-hearth steel, and on May 29th a hammer-head weighing 2535 lbs. was made. As long as the castings were small, the moulding mixture of ground brick, ground pots, and fire-clay was satisfactory; but in large castings the surface was very imperfect, and the sand adhered to it with great tenacity. No improvement was made in this method of moulding for some time, and while the quality of steel was gradually being improved, the appearance of the castings was decidedly against them, and but little progress was made in their general introduction.

"The next step was to leave the ground pots out of the moulding mixture and to wash the mould with finely ground fire-brick. This was a great improvement, especially in very heavy castings; but this mixture still clung so strongly to the casting that only comparatively simple shapes could be made with certainty. A mould made of such a mixture became almost as hard as fire-brick, and was such an obstacle to the proper shrinkage of castings, that, when at all complicated in shape, they had so great a tendency to crack as to make their successful manufacture almost impossible. By this time the use of silicon had been discovered, and the only obstacle in the way of making good castings was a suitable moulding mixture. This was ultimately found in mixtures having the various kinds of silica sand as the principal constituent. In 1887 the Midvale Steel Co. took a contract for gun-carriages

to stand a ballistic test, and filled it successfully. These were the first castings made under such specifications, and it was about this time that the steel-casting business began its rapid growth to its present dimensions.

"In comparing steel and iron castings with reference to their freedom from flaws, we must remember that steel castings, as a rule, are subjected to a very much more rigid inspection than iron castings are, and are generally condemned for more insignificant defects. If the metal is hot enough, it is possible to pour castings of an exceedingly thin section and with very sharp edges with entire satisfaction.

"One of the most fertile sources of defects in castings is a bad design. Very intricate shapes can be cast successfully if they are so designed as to cool uniformly. While I am not yet prepared to state that anything that can be cast successfully in iron can be cast in steel, indications seem to point that way in all cases where it is possible to put on suitable sinking heads for feeding the casting.

"With regard to the economy in the use of steel in the place of iron castings there is much to be said. At the works of the Midvale Steel Co. their use has been long regarded as an insurance against breakdowns. The great cost of steel castings is not at all proportional to the increase in working strength, which, in properly made and annealed steel castings, can be safely taken as at least four times as great as that of the ordinary cast iron casting. It is often, in fact usually, impracticable to reduce the section of the casting in this proportion, but a greater saving can always be obtained by proper designing.

"With regard to our success in making castings of large area and complicated character, I may state that it has been quite good, but that the work requires moulders of great experience, and is exceedingly expensive. Castings involving large variation in thickness are always difficult, but in many cases the difficulty may be overcome. Difficult cores very materially increase the expense of the casting, but we are gradually overcoming difficulties which a few years ago were thought to be insuperable."

During the period of Naval Reconstruction, the company which I have the honor to serve as Superintending Engineer has built and is building for the Navy ten ships, with two more recently awarded, varying in displacement from the "Vesuvius"

of 800 tons to the "Iowa" of 11,300, and thirty triple-expansion main propelling engines, of which sixteen work in pairs on twin screws, eight work in two sets of pairs on twin screws, and six in sets of three on triple screws; these engines vary in power from 1700 each in the "Yorktown" to about 7000 each in the "Columbia" and "Minneapolis." Eight of them are horizontal and twenty-two vertical. Cast steel has been used for bed-plates and frames in four of the horizontal and in all of the vertical engines, except the "New York," whose Y columns are of cast-iron on cast-steel bed-plates. The bed-plates of the "Yorktown" and the "Newark"—four engines—are of cast-iron. Perhaps it may be worth while to remark that the "Newark's" engines, notwithstanding their cast-iron bed-plates, have exhibited a higher coefficient of performance than any other cruiser engine yet put on trial; her proportion of indicated horse-power to weight of machinery, to square foot of grate surface, and to amount of coal consumed being greater than that of any other engines of the new Navy having steel bed-plates—excepting of course the "Vesuvius," which cannot fairly be considered as in the same class for comparison. However, the metal put into the "Newark's" bed-plates was gun-iron of the highest quality—better perhaps than has elsewhere been used for a similar purpose.

In the later group of navy engines, designed by the Engineer-in-Chief, the bed-plates are cast steel, in sections bolted together longitudinally, and the supports are half Y columns of cast steel at the back and hollow forged-steel columns at the front, the cast columns carrying the guides on their vertical inner faces. No serious difficulty has been experienced in procuring these cast columns, their section being simple and of sufficient thickness of wall to insure a good flow.

While the main theme of this paper is the use of steel castings in marine work, I think it proper to go a little outside that scope to deal briefly with remarkable successes which have been achieved by Messrs. Mackintosh, Hemphill & Co., Ltd., of Pittsburg, better known as "The Old Fort Pitt Foundry," in the direction of steel castings for heavy rolling-mill machinery.

Mr. Hemphill gives his experience in a style so well adapted to the purpose of this paper that I will introduce it in his own phrase. He says:

"We began the manufacture of heavy steel castings for

mill uses a little over ten years ago. At first, too much attention was paid to having castings free from blow-holes, without recognition of the superior value of the greater strength of steel over iron castings, and as a consequence we got castings free from blow-holes and brittle, while the 'unsound' ones were tough. Of course, with the advance of knowledge, this trouble of blow-holes in comparatively soft and tough castings has lessened, but too many users of steel castings still attach a totally unfounded weight of objection to a few blow-holes, neglecting the obvious fact of importance, that the casting is infinitely stronger than any sound iron casting. A steel casting of such size and section that the metal will remain fluid until all dirt, gases, etc., will escape to the top is as sound and free from blow-holes as a similar one of iron; small castings that 'set' quickly generally have some blow-holes—an experience English engineers tell us they have with even Terre Noir castings. Steel has no tendency to chill in the sense of 'chilled iron,' but 'sets' far more quickly than iron. Sometimes steel will not run into as small sections as iron, but this is generally due to its losing heat. Shrinkage is the great difficulty in steel castings, coupled with the fact that this shrinkage is greatest just at the weakest condition of the material, shortly after 'setting,' and engineers display too little comprehension of this important fact, designing shapes on the theory that the founder must bend the natural laws of his material to suit their designs, instead of their endeavoring to meet these laws. It is in the shrinkage more than in the running of the metal that intricacy of shape is so mischievous. We have never taken into account saving of weight by use of steel castings. Rolling-mill machinery is subjected to the most violent shocks, and the importance of running continuously without breakdowns is supreme, and we aim to make it strong enough as the first point and don't bother about equations of strength and weight. In a general way, we may say that there can be no more comparison between strength of steel and iron castings than between a quart of molasses and a yard of calico. Tensile strengths, elongations, elastic limits, and such qualities can be determined, but the difference between the cast-iron snapping off and the steel bending cannot be measured in figures.

"Mechanical engineers of rolling mills, who are directly responsible for the endurance of machinery they design or approve, are very apt to resort to steel castings in parts subject

to violent shocks, without inquiry whether iron will do as well. If iron will do, steel will do much better, is about the way they size it up ; and the practical results in dollars and cents of the operation of their machinery is much more important with them than abstractions of scientific principles. We find no difficulty in making steel disk-cranks for our heavy reversing engines up to 46×60 inch cylinders, running under 100 lbs. pressure, and have never known such cranks to break."

The principal value of the experience of the Fort Pitt people, in the general sense, is found in their observations on the varying behavior of steel, differing in carbon. They have found, in common with others, and Mr. Hemphill states the fact lucidly, that the tendency of soft, tough, ductile metal is to develop blow-holes to a much greater extent than hard, high and brittle steel. I have understood, on good authority, that in some castings where a considerable factor of ductility or toughness was required, such as roll driving-shafts and couplings, their furnace charges embraced as much as 45% of imported low-phosphorus scrap, and that for this particular purpose they have not succeeded in finding any domestic scrap that could take its place.

In large roll driving-pinions of the V-toothed type, which form quite a specialty of theirs in steel, they use a much harder and higher metal, as rigidity rather than elasticity is required, and an obdurate wearing surface is desirable.

But Mr. Hemphill's remarks as to the effect of the existence of blow-holes suggest a comment which must have occurred to every manufacturer who has made steel castings under the rigid system of inspection in vogue. This is the fact that too many good castings have been rejected on account of small blow-holes, often mere pits, in machinery faces and edges. This has been the case frequently with pistons, eccentrics, and pedestal-blocks. Of course no responsible manufacturer would desire to turn out an engine part of such importance having serious defect. But in some instances castings have been rejected for showing when machined a few holes or pits the size of a No. 4 or No. 6 bird-shot, notwithstanding that the range of physical qualities has been shown by regular test to be much above the requirements.

Naturally, the steel-founders, when confronted with condemnation for such trifles, which were never real defects, and

hardly ever more than slight surface blemishes almost impossible to avoid, have been discouraged. I will not be excelled by any one in stickling for a high standard, but there should be considerable room for exercise of mechanical commonsense in the modes of inspection of steel castings.

I think it proper to say, having had experience in both directions, that recent development of the steel industry in the United States as compared with its state abroad presents a much more gratifying progress in forgings and rolled material than in castings. Our great forges, such as Bethlehem, thanks to the genius, energy, and diligence of the venerable John Fritz and his co-laborers, are now quite abreast of any in the world, if not actually in the lead. Our principal rolling-mills, in operation at many points, from the Chesapeake Bay to the head of Lake Superior, with another, among the most important, about to start up on Puget Sound, have no odds to ask of any foreign mills in any description of plates, shapes, or structural material.

But it must be confessed that our steel-founders have not yet reached an equal grade of excellence as compared with those of Great Britain, France, or Germany.

It may be that, with the great and sudden expansion of the volume of business, together with the high prices ruling, many new enterprises have started, and there has been a disposition to perfect the new organizations at the expense of the older ones by inducing away the leading men of the latter as soon as they had acquired valuable experience. This is, of course, true of all trades, and will in time correct itself; but it seems to have affected the cast-steel industry with peculiar force in the last few years—at all events, to a much greater extent than is true of the other branches of the steel industry. Then, again, the growth of competition has led some foundries to attempt cheapening of their cost of production, which could be done only by use of inferior raw material or employment of less skilled assistance. This is the policy that never fails to be fatal to any establishment which may adopt it.

However, in conclusion, I would say that, when it is borne in mind that none of these great industries now domesticated in our midst date back as much as a decade, we may be fairly content with the results achieved, and confidently trust to the natural development.

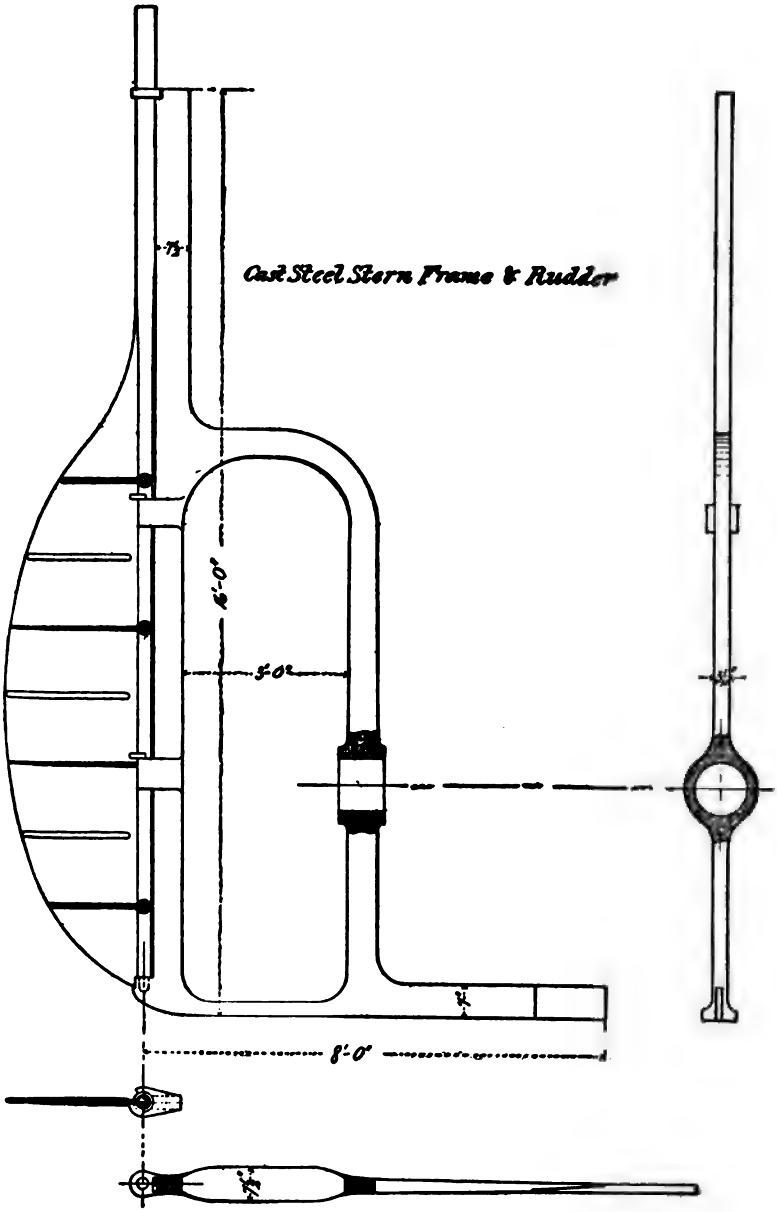


PLATE I.

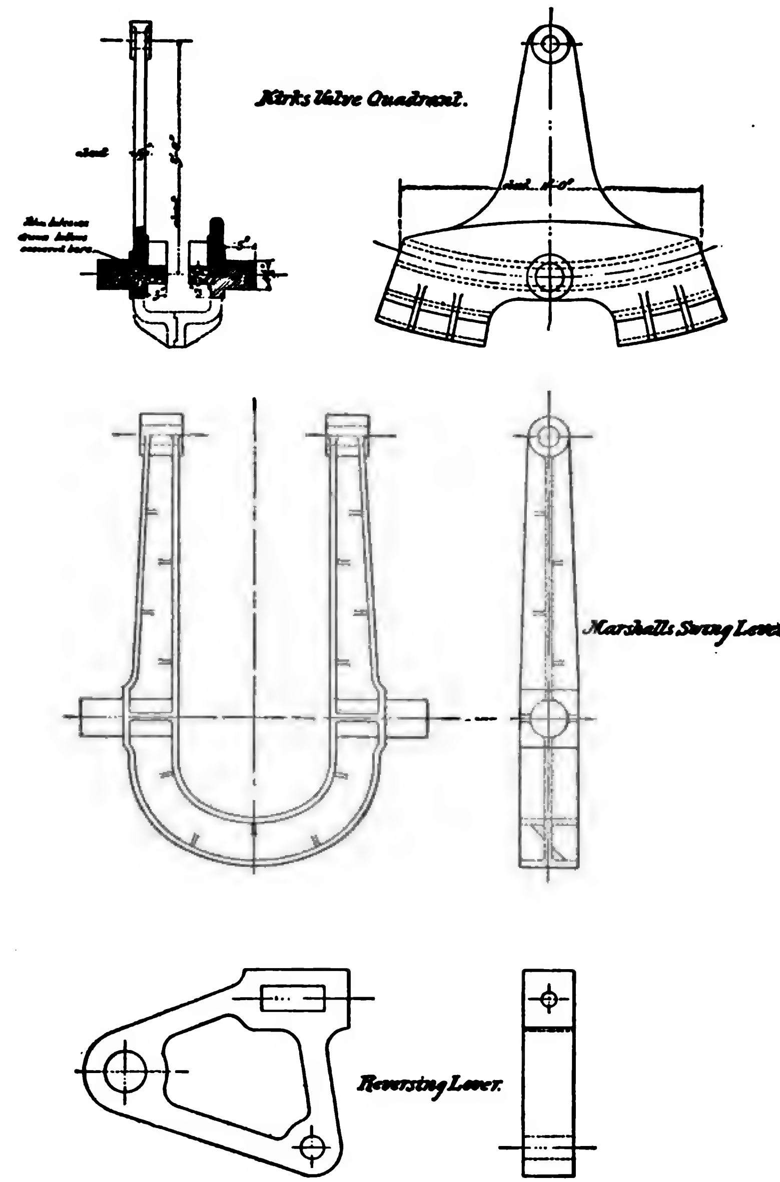
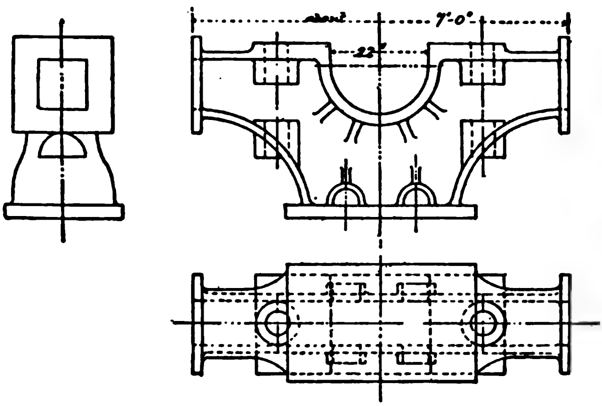
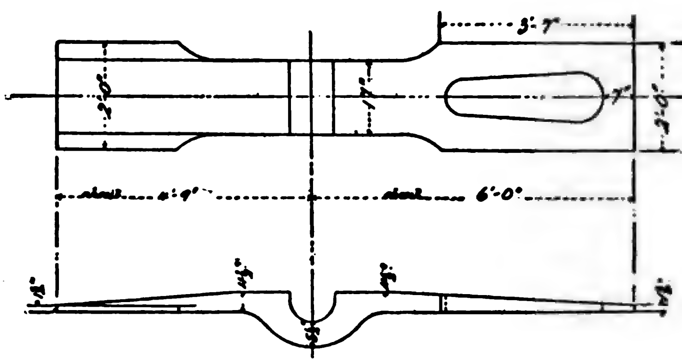

Kirk's Valve Quadrant.
Marshall's Swing Lever
Reversing Lever.

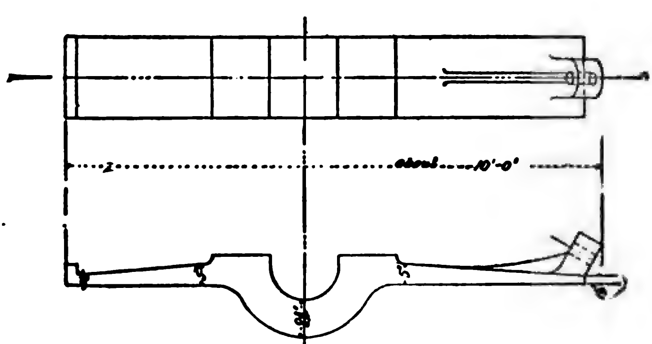
PLATE II.



Main Bearing · Vertical Engine

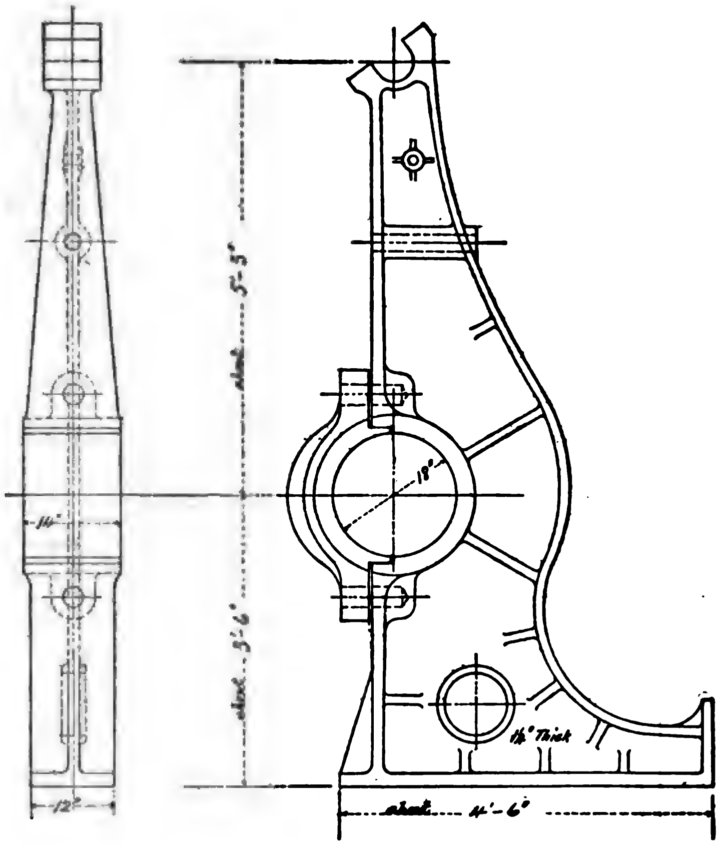


Slab Bed Plate Vertical Engine

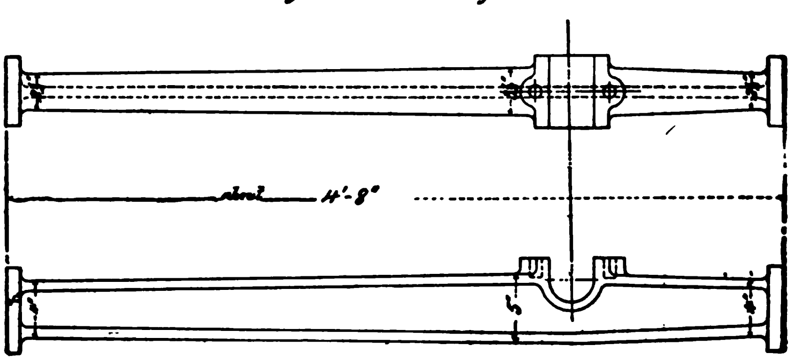


Slab Bed Plate Vertical Engine.

PLATE III.

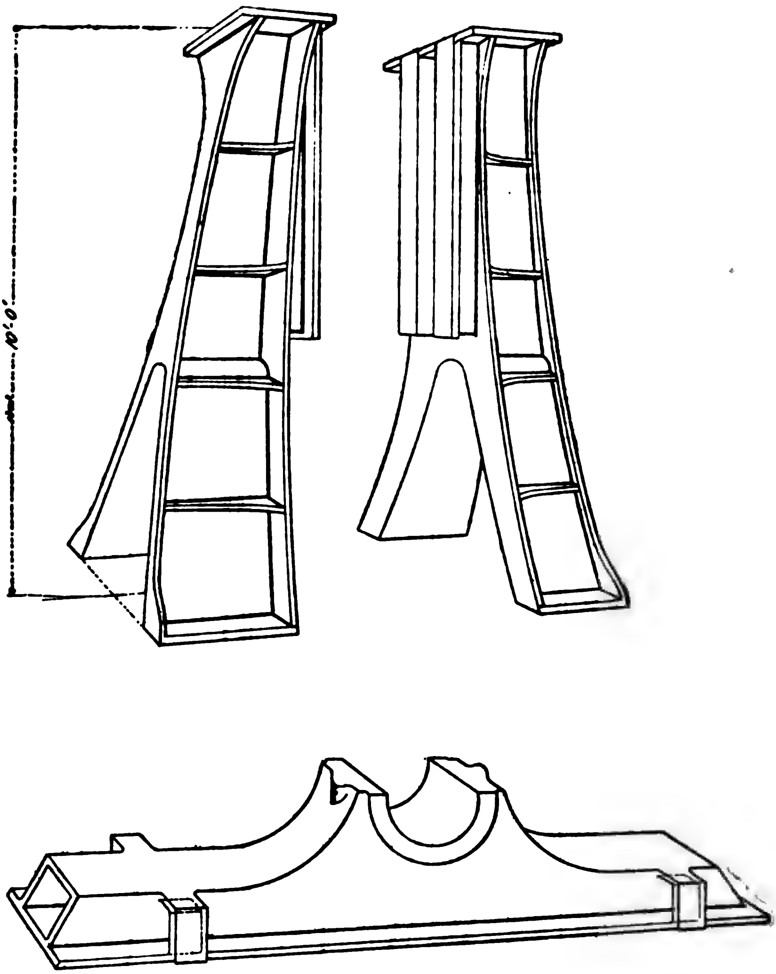


Framing Horizontal Engine.



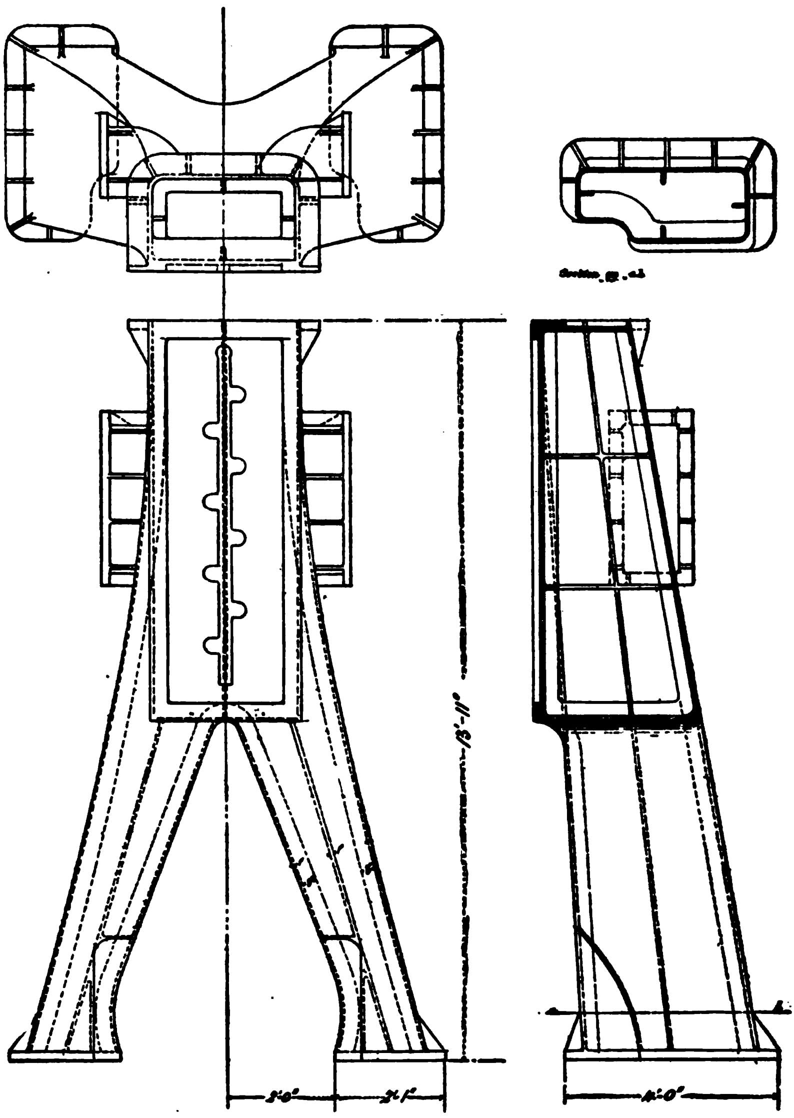
Tie Rods for top of frames of Horizontal Engine.

PLATE IV.



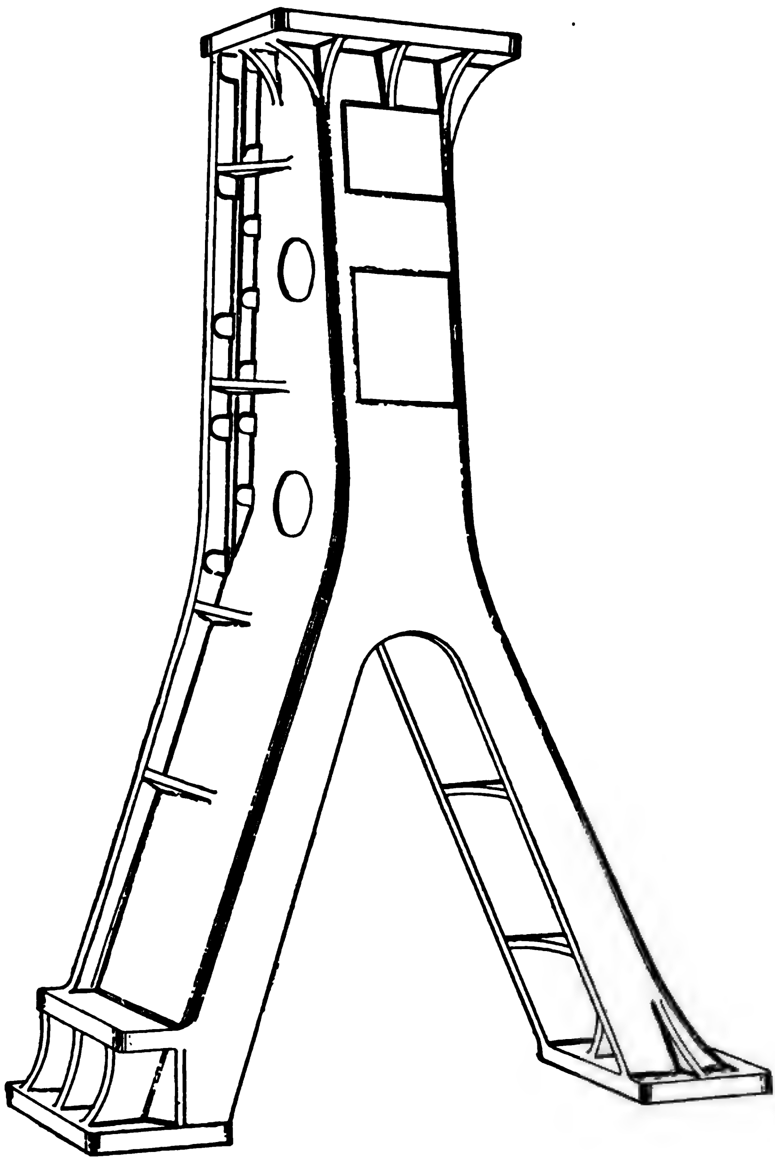
Steel Castings.

PLATE V.



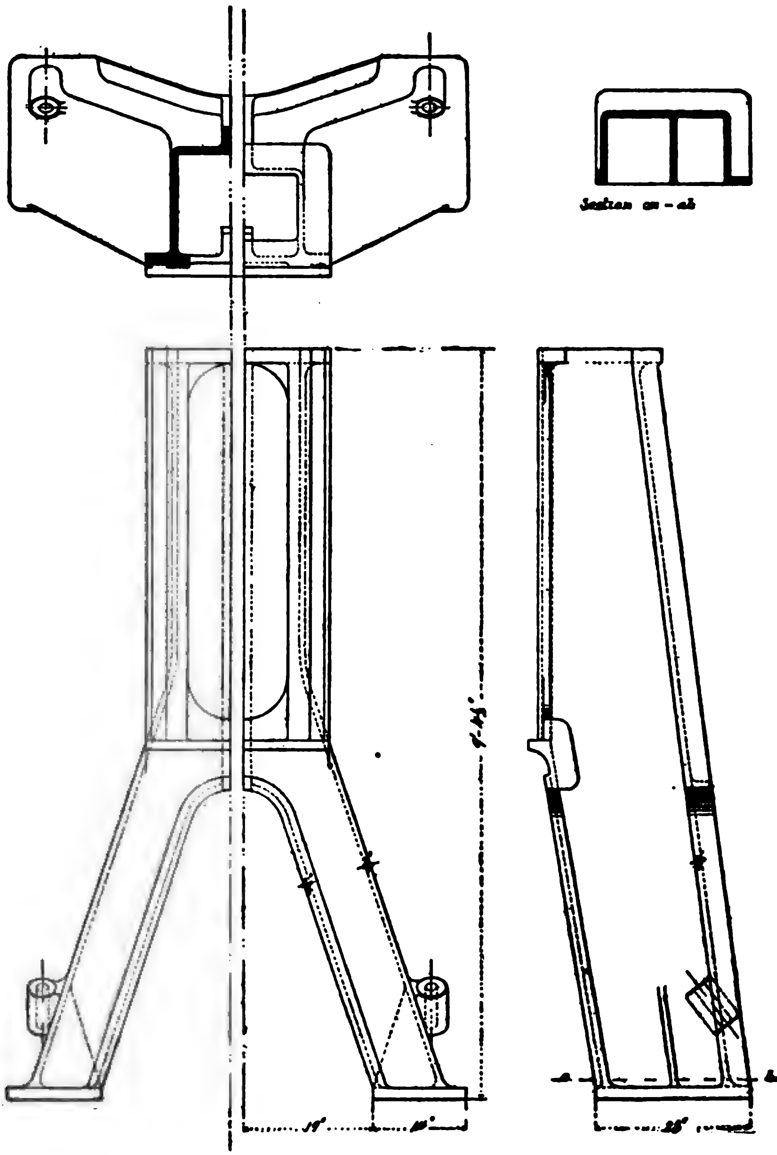
Steel Column.

PLATE VI.



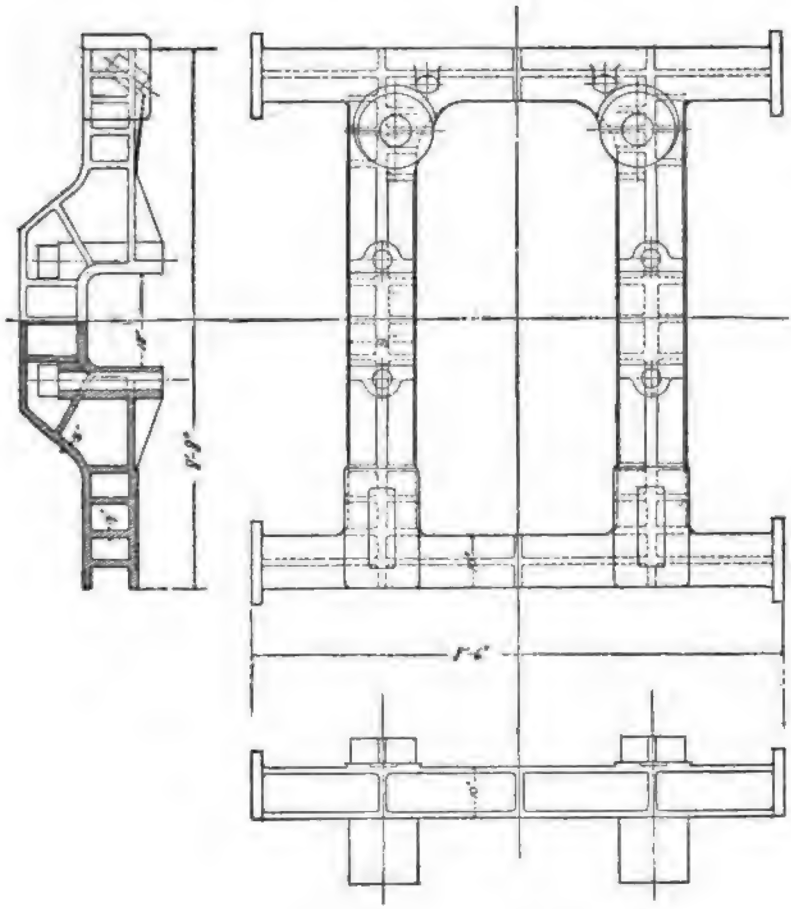
Steel Column.

PLATE VII.



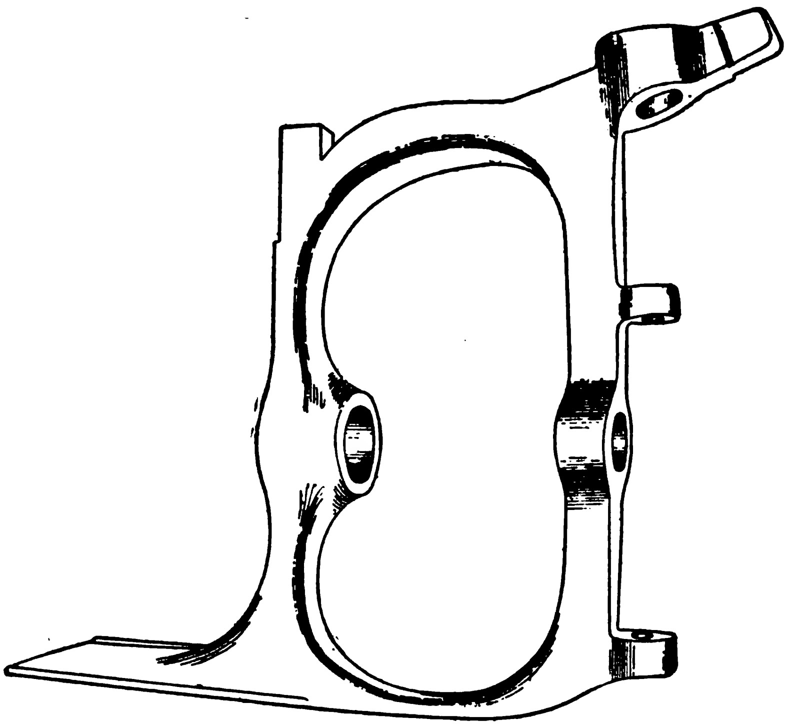
Steel Column.

PLATE VIII.



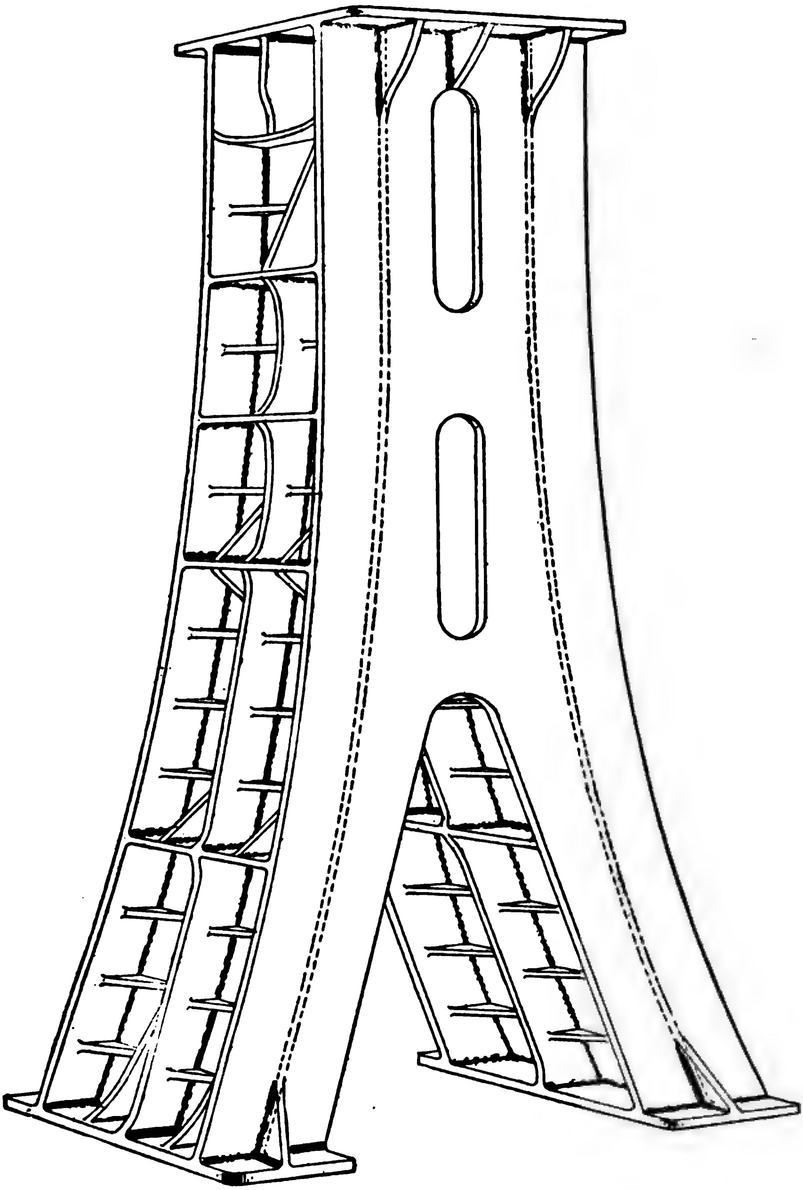
Bed Plate.

PLATE IX.



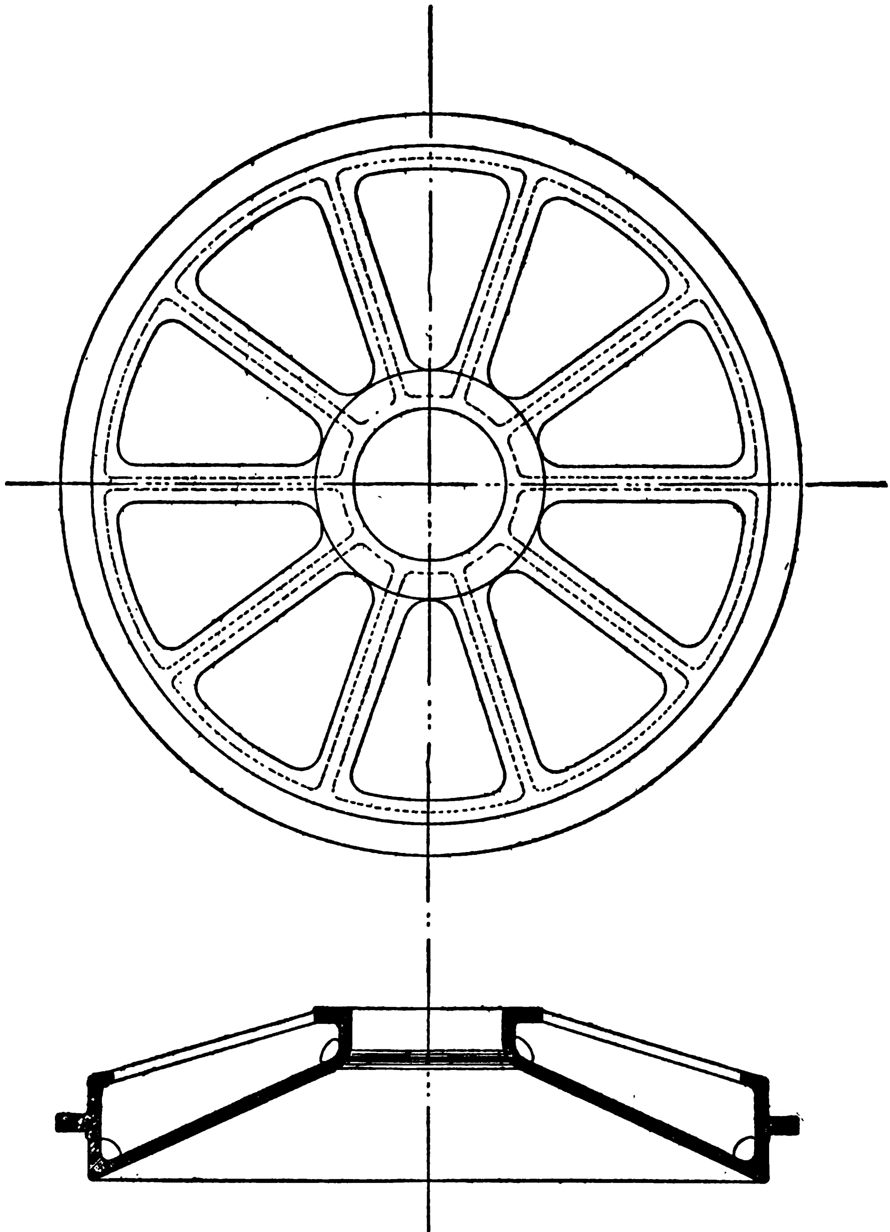
Stern Post.

PLATE X.



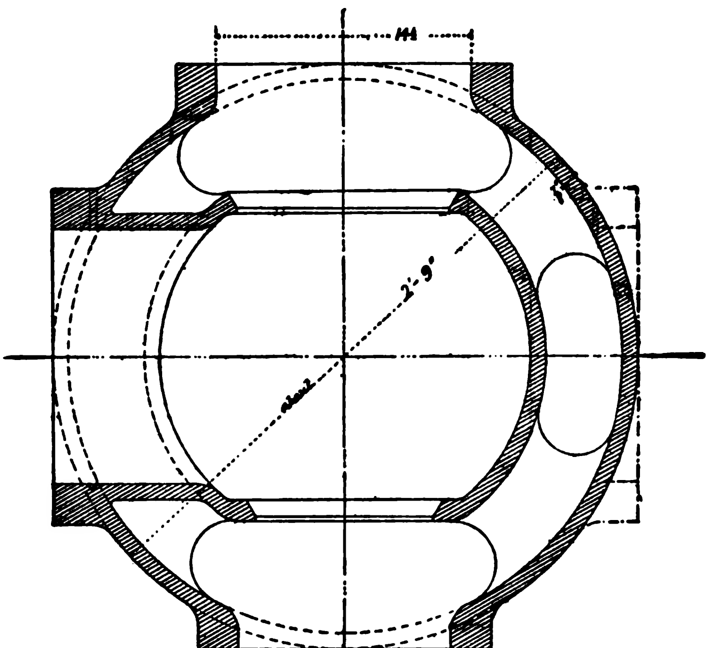
Steel Column.

PLATE XI.



A Cylinder Cover $\frac{7}{8}$" to 1" thick.
Diameter about 88"

PLATE XII.



Double Beat Valve.

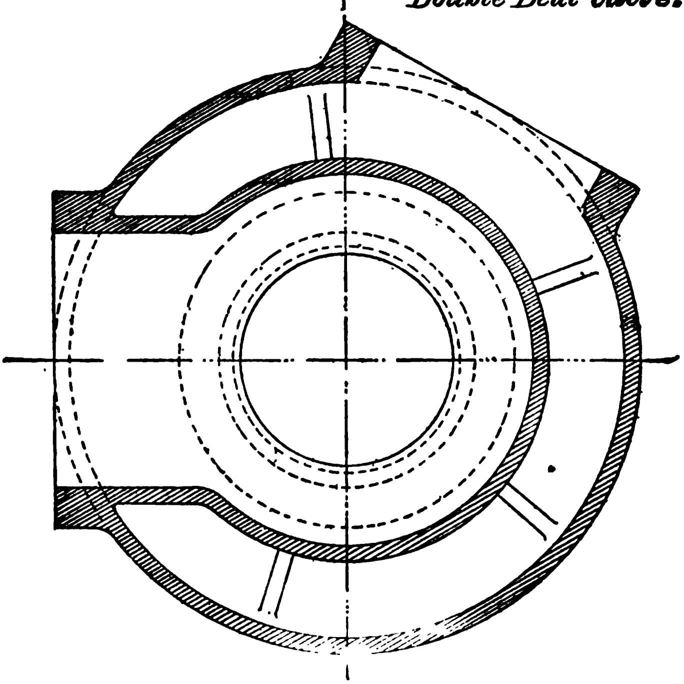
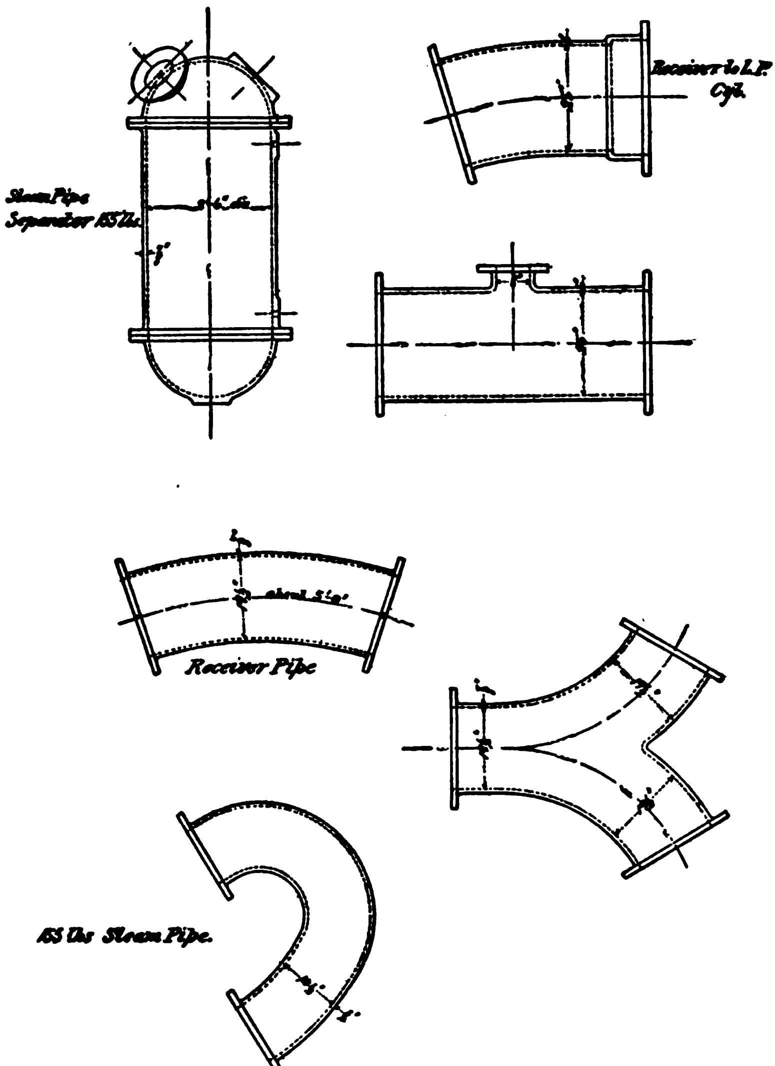
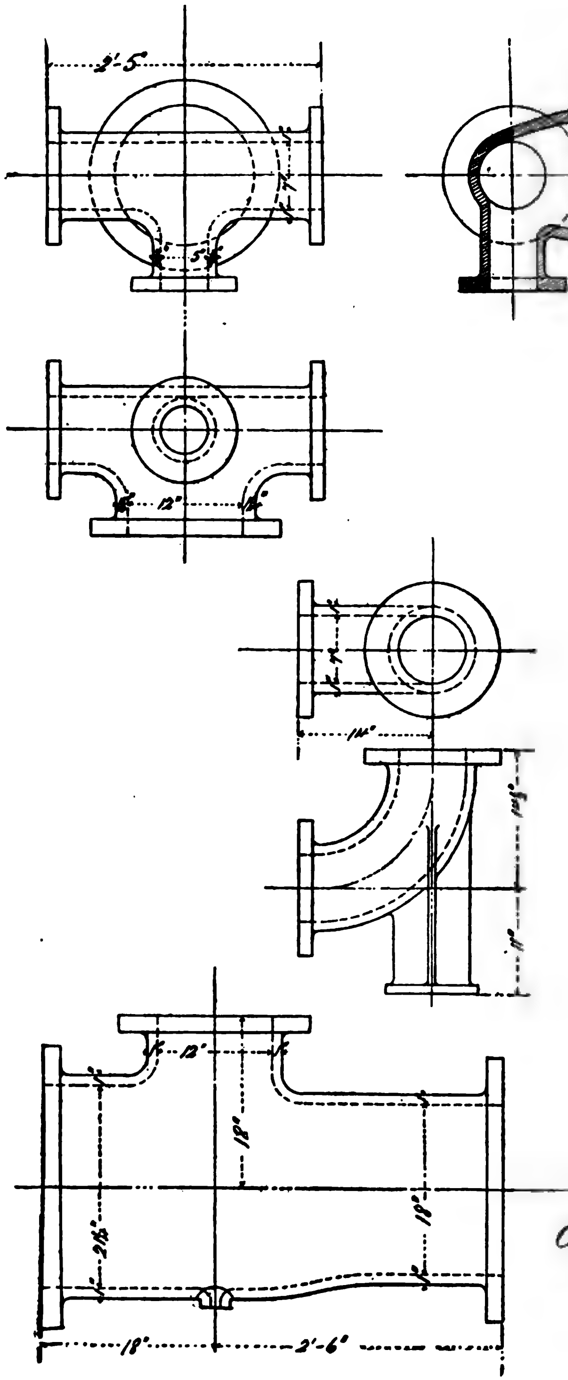


PLATE XIII.



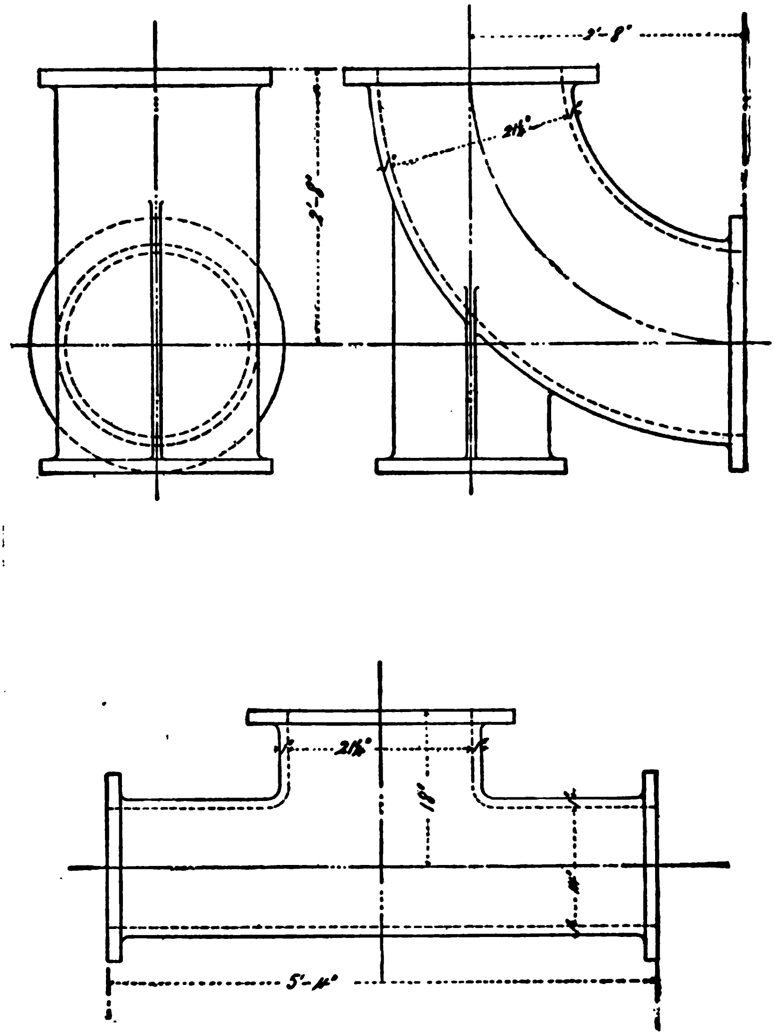
Cast Steel Pipes & Separator.

PLATE XIV.



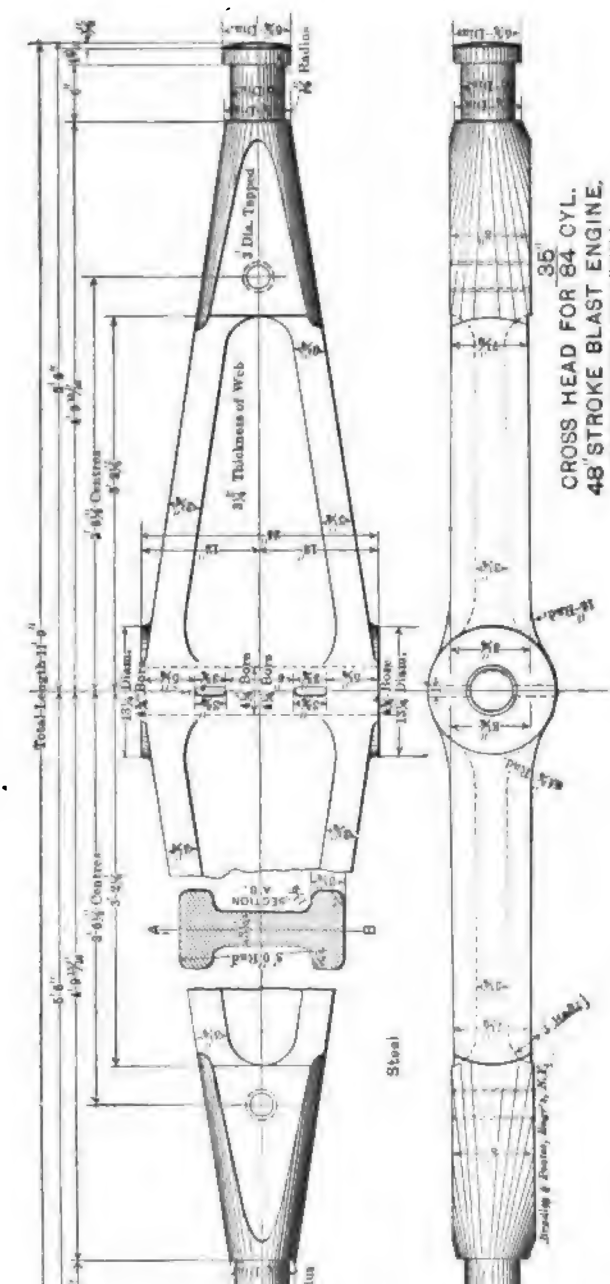
Cast Steel Pipes.

PLATE XV.



Cast Steel Pipes.

PLATE XVI.



CROSS HEAD FOR $\frac{35''}{84''}$ CYL.
48" STROKE BLAST ENGINE,
MACKINTOSH, HEMPHILL
& CO., LIMITED.

PLATE XVII.

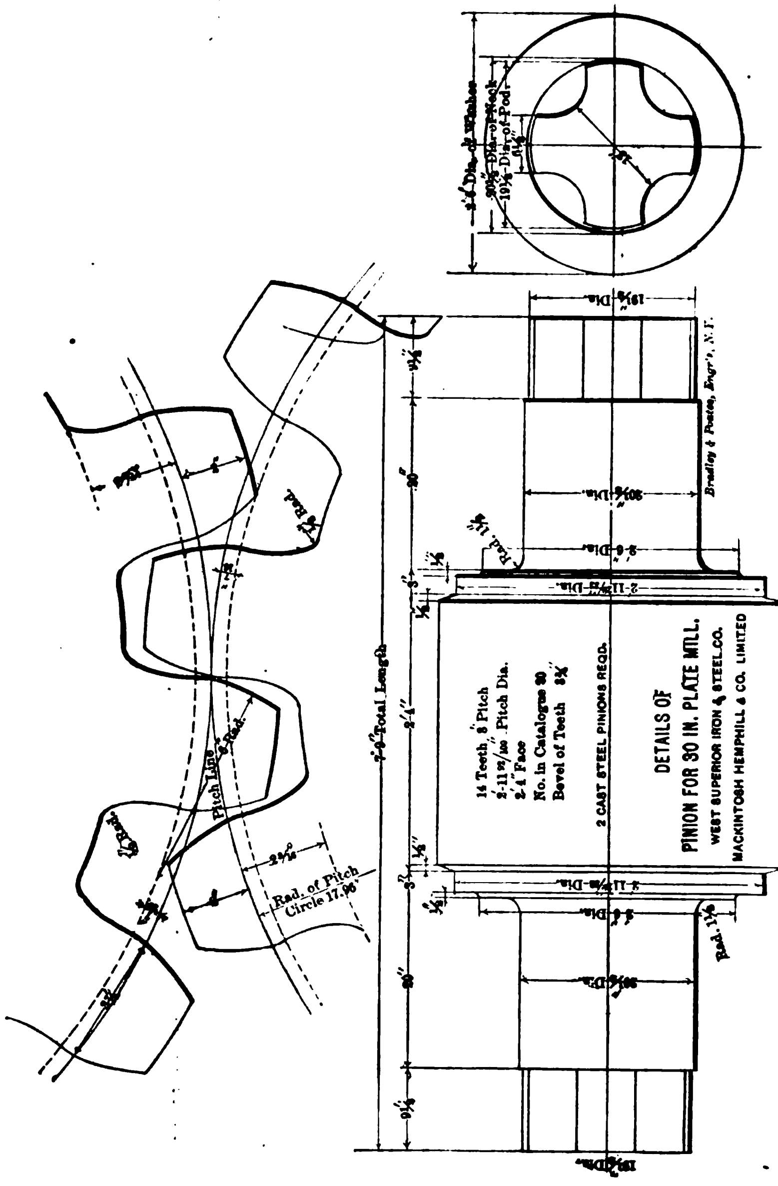

14 Teeth, 8" Pitch
2'-11 92/100" Pitch Dia.
2'-4" Face
No. in Catalogue 20
Bevel of Teeth 3/4"
2 CAST STEEL PINIONS REQD.
DETAILS OF
PINION FOR 30 IN. PLATE MILL.
WEST SUPERIOR IRON & STEEL CO.
MACKINTOSH HEMPHILL & CO. LIMITED
7'-8" Total Length
Pitch Line
Rad. of Pitch Circle 17.96"
Bradley & Poates, Engr's, N.Y.

PLATE XVIII.

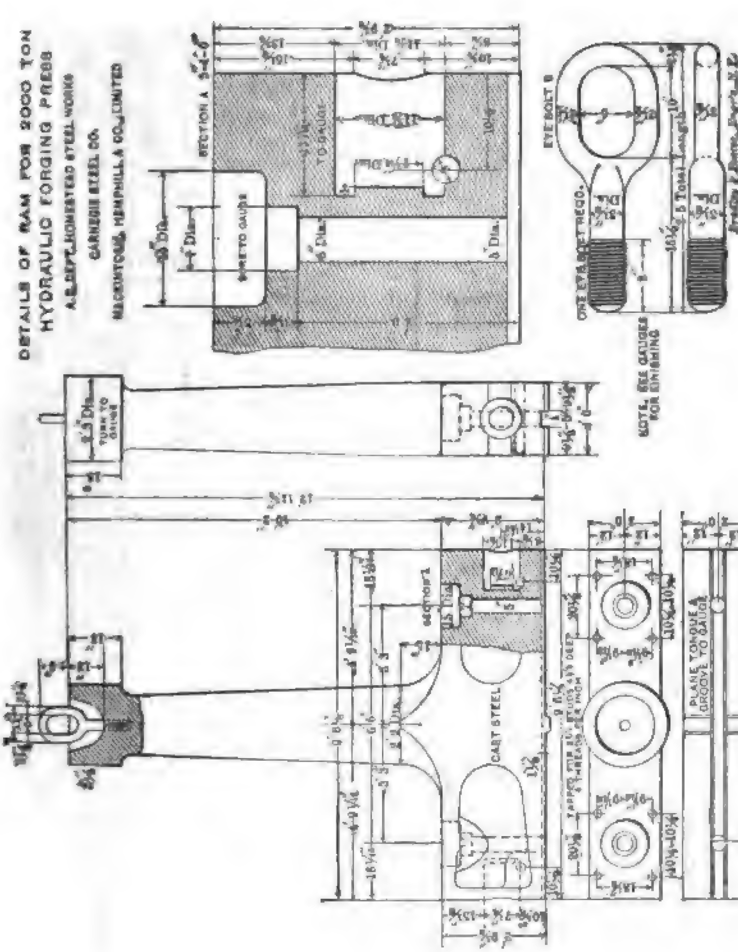
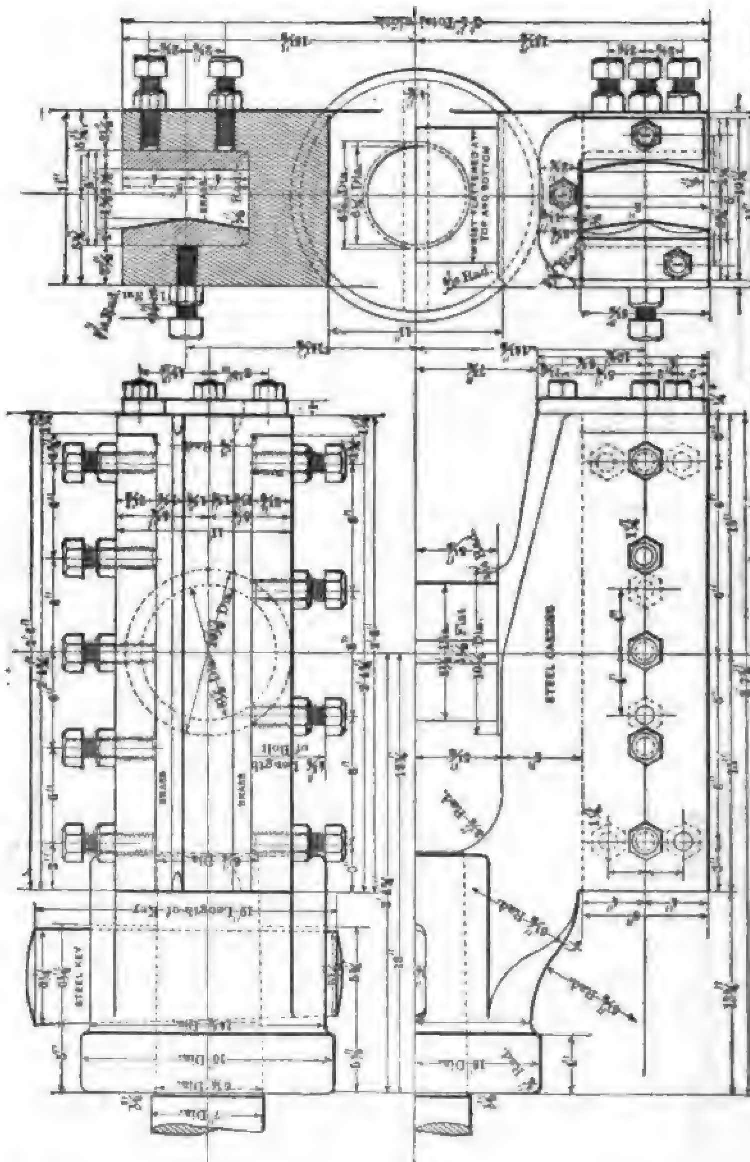

DETAILS OF RAM FOR 2000 TON HYDRAULIC FORGING PRESS
A.S. DEPT. HOMESTEAD STEEL WORKS
CARNEGIE STEEL CO.
MACKINTOSH, HEMPHILL & CO., LIMITED
SECTION A
EYE BOLT B
CAST STEEL
NOTE. SEE GAUGES FOR FINISHING
PLANE TONGUE & GROOVE TO GAUGE

PLATE XIX.

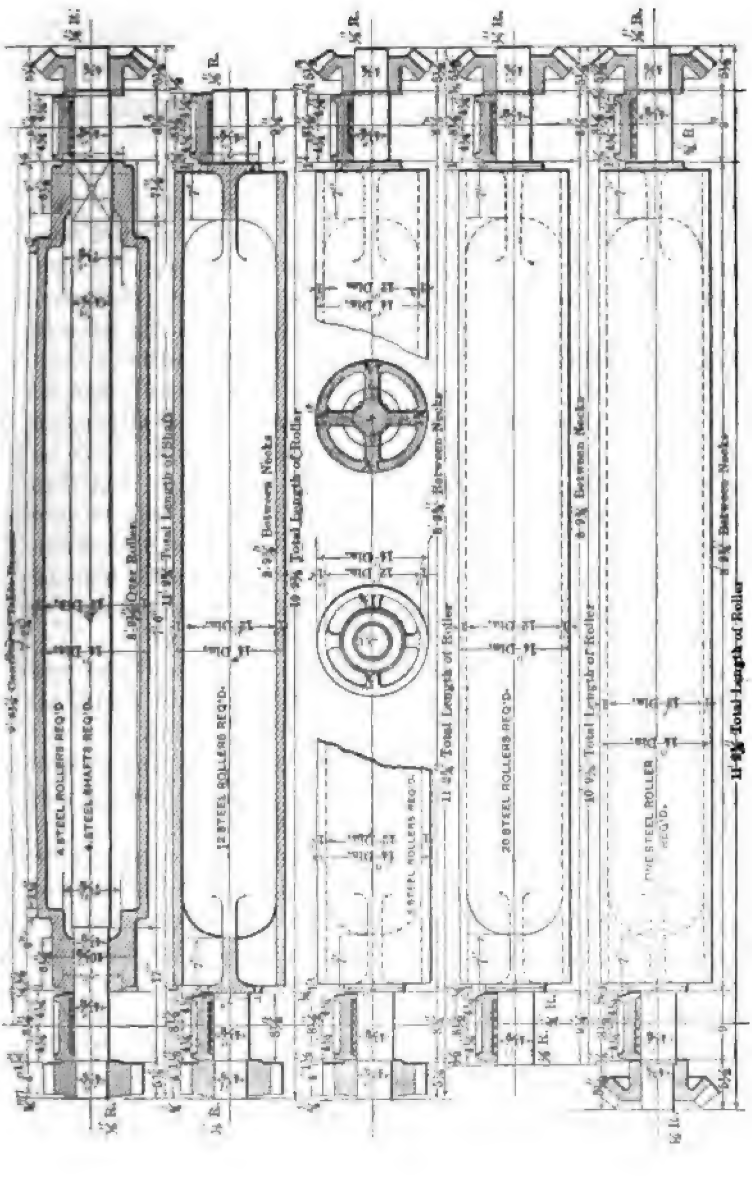


DETAILS OF CROSS HEAD FOR 48" X 48" AUTOMATIC ENGINE

FOR THE CARSON IRON CO.

MACKINTOSH, HEMPHILL & CO., LIMITED

PLATE XX.



DETAILS OF TABLE ROLLERS FOR 30 INCH PLATE MILL, WEST SUPERIOR IRON AND STEEL CO., MACKINTOSH, HEMPHILL & CO., LIMITED.

PLATE XXI

DISCUSSION ON STEEL CASTINGS AS USED IN MARINE MACHINERY.

MR. JNO. C. KAFER:—The paper by Mr. Cramp on Steel Castings gives the state of the art at the present time, with the many difficulties encountered since they have come into use. We know well, as the chairman of this division has found out, that steel-casting companies will promise almost anything; but the difficulty has been in getting castings of a uniform quality, without flaws, and of a uniform strength and ductility. The trouble has not been to get any particular high test either as to tensile strength or ductility, but to get several castings identical in quality. The improvement in the uniformity of material within the last three or four years has been so marked that we may now hope to order castings and be sure that they will be reliable. The illustrations of the various kinds of castings that have been made are very useful, and show the care that must be taken in making the patterns to insure castings that are solid and without flaws.

I wish that Mr. Cramp had said a little more about the cores used in steel castings, the material of which they are made, and their rigidity, as the core work is the most difficult part.

PROF. IRA N. HOLLIS:—There is very little to comment upon in Mr. Cramp's clear presentation of the present status of steel castings. Numerous cuts leave nothing to be desired.

I agree with him that common-sense should enter largely into the inspection of steel castings. Common-sense is largely a matter of experience, however; and many castings were rejected five years ago which would be passed now, because neither the inspectors nor manufacturers then had a practical knowledge of the subject. Surface blemishes appeared to be serious then, but experience in actual use has established the fact that many apparently imperfect castings are really reliable and safe.

The use of steel castings for valve-chambers presents an interesting question; that is, the effect of heat upon the tightness of the valves. The brass valve chambers now in use expand so much more than cast iron under steam heat, that the seats change shape and cause leaks which cannot be checked with large valves. I

have always believed in the use of cast iron for valve-chambers. If steel has a low coefficient of expansion, we get all the advantages of cast iron with greater strength and reliability than brass.

The future of steel castings seems encouraging, now that we have a definite knowledge of their limitations and the method of manufacture. When they were first introduced into this country everything was to be made of steel; now we know very well, as stated by Mr. Cramp, that castings of complicated shape and great variations of thickness cannot be made successfully of steel. The designer has come to recognize the necessity of designing for the metal, instead of using the metal for any design.

XXXV.

ON THE FORM AND TREATMENT OF TENSILE SPECIMENS WITH REFERENCE TO THE TESTS OF IRON AND STEEL.

By JAMES E. HOWARD, C.E.,

Engineer of Tests, U. S. Arsenal, Watertown, Mass.

THE physical properties to be investigated will exert the controlling influence in limiting or defining the form and dimensions of the test specimens. If a complete exposition of the physical properties is sought, the material must be in such form as to admit of their unrestricted development. Special uses of metals may require for investigation special types of specimens, in which the conditions of service are in whole or in part reproduced. This appears to be a fundamental statement of the case.

That modifications in results may be introduced by change in form and dimensions has long been recognized, and many illustrations have been furnished showing the different numerical values obtained under different conditions of test-piece. In order to understand why such modifications in results may be expected in tensile specimens, a discussion in detail of the properties developed by testing is called for.

Those properties generally regarded as important to observe may be enumerated as follows:

Elastic limit;

Tensile strength;

Total elongation;

Contraction of area at place of rupture;

Character of the ruptured surface.

The observations may be extended so as to include the

determination of the modulus of elasticity, the elongation under loads between the elastic limit and time of reaching the maximum load or tensile strength, with the permanent sets corresponding thereto and the stress in the metal at the time of rupture.

In cases of greater refinement, without introducing material change in the temperature of the test-piece, which, it may be remarked in passing, appears to effect a change in all of the tensile properties, observations may be made upon the changes in volume while under stress by determining the lateral contraction in conjunction with the longitudinal extension of the metal, the temporary reduction of the modulus of elasticity due to overstraining, the rate of extension under the influence of stresses above the elastic limit, with the element of time as a function, and the effects which lapse of time alone causes in overstrained material.

We may also gather data tending to show the ability of the metal to endure local changes in density, or to receive and retain internal strains. The effects of long-continued and repeated stresses on the phases of deterioration passed through before ultimate rupture may be investigated. All this information may, perhaps, be necessary before we shall fully understand the significance of an ordinary tensile test.

The relations which exist among the several properties, and the influences which promote durability in metals, we must admit, are in a state of deep obscurity. All of the features enumerated are doubtless important at times, their relative importance varying according to the application of the material in the constructive arts. We will narrow the field of discussion, at the present time, by referring only to the group of physical properties first mentioned, not dismissing from mind, however, all ideas associated with the more complex sides of the question.

First considering the *Elastic Limit*.

It does not appear important to limit the rate of application of stresses inferior to the elastic limit, as the full strain due to those stresses which do not cause appreciable permanent set is immediately reached. Such at least has been the result with transversely loaded rotating shafts in which the speed of rotation has caused the metal to pass from a state of zero stress to the maximum in $\frac{1}{75}$ of a second. Such a

rate of speed in applying loads is, of course, not attainable in ordinary tensile tests.

When permanent sets begin to develop, the time element becomes an important factor; the response of the metal to applied stresses is now more or less sluggish. This seems to be the case whatever the form of specimen, although certain forms assist the viscosity of the metal in retarding the development of permanent set; in other forms very little influence of the kind exists. In a short bar with enlarged ends the reinforcing metal exerts a very decided influence in retarding elongation, and, if the bar is short enough, the retarding influence of one end merges into that of the other, and an apparent elevation of the elastic limit results.

The following results of the tests of six specimens from the same 1¼" steel bar illustrate the apparent elevation of elastic limit and the changes in other properties due to change in length of stems which were turned down in each specimen to .798" diameter.

Description of stem.	Elastic limit. Lbs. per sq. in.	Tensile strength. Lbs. per sq. in.	Contraction of area, per cent.
1.00" long	64,900	94.400	49.0
.50 "	65.830	97,800	43 4
.25 "	68,000	102,420	39.6
Semicircular groove, .4" radius	75,000	116,380	31.6
Semicircular groove ¼" radius	86,000, about	134,960	23.0
V-shaped groove	90,000, about	117,000	Indeterminate

These tests show the progressive elevation of the elastic limit as the stems of the specimens were shortened, and the corresponding effect upon the tensile strength. The contraction of area, of course, diminishes as the other two features increase in values.

The lower tensile strength of the specimen having the V-shaped groove was probably due to the excessive concentration of stress at the bottom of the groove from inability to elongate or contract, fracturing the metal more in detail than happened to the other specimens.

In approaching the elastic limit of ductile specimens, a prolonged effort might change the result in certain cases. In some specimens which displayed a jog in the tensile curve near the elastic limit there appeared to exist an unstable

condition of the metal in that vicinity. An instance of this kind occurred: a load was applied, slightly in excess of the elastic limit, and the immediate elongation noted. While sustaining this constant load no measurable increase in elongation occurred during the next fifteen minutes, but at the expiration of that time rapid stretching set in, the load on the specimen dropped 7000 pounds per square inch, and stretching continued under the diminished load.

After the jog occurred in another specimen, its behavior was watched for a period of one hour, during which time the metal continued to stretch, at first rapidly, then gradually diminishing its rate of flow. The stretching had almost but not quite ceased at the end of the hour, as shown by one more observation made twenty minutes later.

It seems highly probable in the first example that permanent elongation was really in progress during the fifteen minutes of apparent repose, only the changes were too minute to be detected by our apparatus—a more reasonable supposition, it would appear, than to assume that a state of rigidity was overcome and flow initiated by the continued action of a stress which did not at once excite such movement.

This jog in the tensile curve which characterizes some metals may be destroyed by first overstraining the metal with a compression load.

The ratio of elastic limit to tensile strength is not a constant one, but varies with the chemical composition of the metal and with the mechanical treatment received. A knowledge of the three features, elastic limit, tensile strength, and elongation, may indicate by what means specific results were attained, and whether the effects of chemical composition have been in a measure obscured by mechanical treatment.

Although reinforcement of section has brought about elevation of elastic limit in specimens thus far observed it does not follow necessarily that such would always be the result. Assuming any part of the cross-section of the specimen to possess absolute rigidity within the elastic limit, then obviously all stress would concentrate at that place and the elastic limit would be overcome before any other part was strained. Now, in an actual specimen, if by some peculiarity of form increased rigidity was imparted locally in a higher degree than reinforcement in strength, it would seem that concentra-

tion of stress at the rigid zone would overcome the elastic limit earlier than otherwise, and a loss instead of gain in elastic limit would be experienced. Additional tests are necessary for a definite solution of this question.

In specimens of uniform section throughout their length, which are secured to the testing-machine by frictional grips, it is common to find the elastic limit first passed in the vicinity of the grips. It hardly need be remarked that specimens should have ample proportions, whereby these affected sections may be avoided and observations on the effects of the stresses confined to other sections.

The *tensile strength* may be modified by the same causes which influence the elastic limit. A short specimen is strengthened by having enlarged ends, and easy curves connecting the parts differing in sectional area. Experiments covering a range of material from cast-iron to mild steel all point to the conclusion that specimens of uniform section, of substantial length, are necessary for the true development of tensile strength.

In a brittle metal, where flow is almost absent, the elementary parts on each side of the ruptured surface maintain their relative positions practically unchanged by the stress which causes rupture. In all other cases, there appears at and following the stress at the elastic limit a state in which there is considerable freedom to slide along, rotate about, or in some manner change relative positions of the particles before they actually decide upon separating by rupture from their adjacent companions. What we recognize as a satisfactory form of tensile specimen is one in which this viscous flow proceeds unimpeded over a considerable part of its length.

The effect of the grips of the testing-machine on the tensile strength is less conspicuous than in the case of the elastic limit. No large preponderance of specimens rupture in the vicinity of the grips, a reasonable extent of gripping surface having been provided.

The tensile strength may be lowered by reason of want of homogeneity in structure or in chemical composition. Specimens are frequently tested in which the ability to elongate varies in different parts of the test-piece: the brittle portions develop cracks under comparatively low loads, while the tougher portions continue to elongate. The condition of

such metal must be regarded as very unfavorable, and liable to display brittleness as a whole; indeed it seems to be the rule, where dissimilar metals are closely associated, that the characteristics of the brittle metal predominate when ruptured.

It seems possible to neutralize and even reverse the usual strengthening effect of the reinforced or enlarged ends of specimens by such treatment as will exhaust the ductility of the metal in the vicinity of the reinforcing metal. This may be illustrated in a wide specimen taken, from a plate having punched holes, in such a manner that the semicircular sides of two punched holes form the sides of a grooved specimen. In specimens where ordinary conditions obtain and increased strength results from reinforced ends, it is difficult to ascertain how much the length of stem should be increased to provide metal beyond the influence of the ends. There is a probability of being led into error by assuming that measurements on the specimen after fracture would reveal the extent of reinforcement, but it is chiefly from such observations that we must draw an inference, unsatisfactory though it may be. Traced in this manner, it is commonly found in small specimens that evidence of reinforcement is confined to the first inch section at each end.

The rate of speed at which rupture is produced is a recognized cause for differences in the results obtained, maximum effects from this cause being reached in the more ductile grades of material. Within the limits of speed attainable in ordinary testing, rapid rupture means higher apparent strength. If these remarks were extended so as to include observations on the behavior of steels at high temperatures, it could be shown that the apparent tensile resistance has been momentarily doubled by rapid rupture, but no such extreme limit has been observed in specimens tested at ordinary temperature.

The *total elongation* is commonly measured after rupture, including both the general elongation of the metal developed by stresses up to and including the maximum load and also the local elongation incident to the contraction of area at the place of rupture developed by diminished stresses after passing the maximum load. There appears no reason why elongation should be measured in this manner except that

common practice sanctions it. Obviously the apparent elongation of a short specimen, which has large contraction of area, reaches a very exaggerated value when defined in this manner.

The elongation should be measured on that part of the specimen beyond the influence of the local contraction next the place of rupture, or else the elongation should be measured before local contraction is developed. Economy in the necessary length of specimen would be promoted by the latter method.

After the maximum stress has been passed, general elongation ceases and the work of completing rupture is confined to the immediate vicinity of the place of rupture. If the elongation was measured at the time of reaching the maximum stress, practically the real elongation of the metal would then be shown.

The omission to discriminate between the effects of contraction of area and true elongation often works injustice in the acceptance of material on the results of physical tests. Cold working may, in some grades of metal, nearly exhaust the elongation without, however, a very decided change having taken place in the contraction of area. Under such conditions a short specimen when measured over the ruptured section would still be accredited with extraordinary elongation.

Specimens have the elongation restrained in the vicinity of enlarged ends. It is customary in the Watertown Arsenal tests to report the elongation of each inch in length, the intervals being laid off on the stem of the specimen before testing. While there is not strict uniformity in the elongation of the specimen beyond the disturbing influences just mentioned, yet the inch sections remote from the place of rupture and from the reinforced ends, if the specimen is of that type, fairly indicate the real elongation of the metal.

The *contraction of area* for its full development requires a specimen of uniform cross-section, for the same reasons as described in referring to the other properties.

The length of specimen over which the effects of local contraction are felt varies with different grades of metal, and the shape into which the ends are drawn down is also observed to differ. In the same grade of metal the ratio which

the dimensions of the fractured surface bear to the original cross-section dimensions is found to differ in different sizes of specimens, referring now to the contraction of plate specimens.

The thinning down of such specimens at the middle of their width in excess of the contraction in thickness at the edges is a matter of common experience. Large contraction of area does not signify necessarily that the metal will elongate well, but a brittle fracture would not readily occur if the metal possessed the ability to contract well and the shape of the metal favored such development.

The fact that local contraction is principally developed under diminishing stresses, after having passed the maximum load, does not recommend this feature as a substitute for elongation, which is developed under ascending stresses, except in those instances where jogs in the tensile curves appear, when there is a temporary diminution of load in the early part of the loading.

The character of the fractured surface ordinarily indicates whether the metal is tough or brittle, more particularly in regard to contraction of area than general elongation. A mild and tough steel may, from some local defect, or from exhaustion of toughness due to repeated stresses, or from association with hard and brittle metal, display in the fracture the characteristics of brittle steel. Under ordinary conditions uniformity in the metal is represented by a uniform appearance in the fracture, and a silky or fibrous appearance is typical of tough metal, just as a granular appearance represents a brittle one.

From what has been said it appears that the values of all of the tensile properties are subject to modification, and from a common cause; but when the test pieces possess ample proportions there will be practically little restriction in the development of these properties, and a close approach to uniformity in results will be attained.

In this paper very little reference has been made to actual dimensions of test specimens or to the range in numerical values encountered with different types of specimens, as it is believed that branch of the subject has been very exhaustively dealt with by others.

The expediency of confining specimens to certain standard

dimensions is interfered with by the fact that the material they represent assumes such an endless variety of shapes and dimensions; however, a classification might be made of material according to its uses, and the minimum dimensions established for specimens of each class.

For the present or until the relations between the tensile properties and the ultimate endurance of material in service are better known, a very careful examination of the material, including as many of the physical properties as practicable, seems to be very desirable, supplemented by a record of the subsequent behavior of the material in service.

DISCUSSION ON THE FORM AND TREATMENT OF TENSILE SPECIMENS WITH REFERENCE TO THE TESTS OF IRON AND STEEL.

COLONEL NABOR SOLIANI:—Regarding tensile tests of materials, I deem it proper to call attention to a paper read by Mr. J. H. Wicksteed at the meeting of the British Association three years ago (Measurement of Elongation in Test Samples; *Trans. British Assoc.* 1890), in which he proposes that, in addition to the total elongation, the uniform or parallel elongation of the sample be measured and taken account of, as the latter is proportional to the length of the sample whatever its cross-section may be, and gives information of the range of stretching the material is capable of undergoing without loss of strength. It allows us also to discriminate between capacity for stretching and capacity for reduction of cross-section.

Uniform elongation goes on in samples when tested, as long as they offer increasing resistance, and therefore it can easily be ascertained.

I only wish this point mentioned in the Proceedings of the Congress.

MR. E. PLATT STRATTON:—I will state that I have given some attention to this paper, and I find that Mr. Howard has followed the subject far more closely than is possible for any of us to have done in practising engineering generally. In the paper which I submitted here I made some tests on the particular form of test-pieces, showing the variation between the test-piece as usually prepared, 8 inches long and 2 inches wide, and that adopted by the Board of Supervising Inspectors. Mr. Howard shows the different forms of testing the variations incident to pulling, on the same conditions, which I think are exceedingly interesting and very instructive. I have not been able to follow the paper through all its details, but it strikes me that he analyzes the subject very thoroughly, and any one reading it will be very much instructed.

XXXVI.

SHIP-BUILDING AND ENGINEERING ON THE GREAT LAKES.

By WALTER MILLER, Esq.,

Superintending Engineer, The Globe Iron Works, Cleveland, Ohio, U. S. A.

THE subject of this paper is a very interesting one to those who have given the matter enough study to comprehend the size and extent of the tonnage afloat on these inland seas at the present time, and it could be elaborated almost indefinitely, commencing with the earliest sail and steam craft, considering the size, tonnage, and power of each, and going on to the modern steel, twin-screw steamer of the present day. It is not within the limits of this paper to do this, and I shall take it up from 1881, a period when the adoption of iron as a ship-building material, and the introduction of compound engines for the propelling power, began to be considered, which have resulted in building up an industry whose growth has been considered phenomenal.

Ship-building and engineering on the lakes have their periods of prosperity and depression as have other industries in other localities. These periods of prosperity and depression do not seem to occur with any regularity, but depend largely upon the fluctuations in the demand for iron, grain, etc., as the vessels on these inland seas are engaged to a large extent in transporting the iron ore from the mines on the upper lakes to ports on the lower lakes, as well as large quantities of grain in bulk from the northwest to the eastern termini.

Some idea of the tonnage transported may be obtained from the report issued by the Bureau of Statistics, Treasury

Department, on the freight traffic of the Great Lakes in 1890. It is a summary of the entire coastwise and foreign business. As the figures of this summary are official, they are given here in full:

SUMMARY OF LAKE TRAFFIC FOR 1890.

	Tons.
Freight carried in the United States coastwise trade	28,295,959
" " " " " " foreign "	2,003,047
Total freight carried to or from U. S. ports...	30,299,006

	Tons.
Flour and grain	4,271,346
Iron ore	9,132,761
Coal	5,735,299
Lumber and lumber products . . .	6,869,660
All other merchandise	2,286,893
Total	28,295,959

UNITED STATES TRAFFIC ON DETROIT RIVER.

	Tons.
Coastwise down	15,344,433
" up	5,771,164
Foreign down	463,282
" up	309,593
Total	31,888,472

Another part of the report makes some very interesting comparisons with the commerce of the prominent ports of the United States and foreign countries; and a still better knowledge will be obtained of the magnitude and importance of the traffic of the Great Lakes. The total tonnage of entrances and clearances, foreign and coastwise trade, of Chicago and Buffalo, for the season of 1890, are thus compared:

	Tons.
Chicago	10,288,868
Buffalo	9,560,590
London	20,962,534
Liverpool	16,621,421
Glasgow	5,977,860
Hull	5,061,882

The entrances and clearances in the foreign commerce of the following prominent foreign and home ports will appear in the following table:

	Tons.
Havre	4,418,876
Marseilles	7,392,556
Antwerp	8,203,999
Hamburg	10,417,096
Bremen	3,481,769
New York	12,646,555
Boston	2,676,387
Philadelphia	2,585,866
San Francisco	1,986,483

By these comparisons it will be observed that the commerce of the two inland cities, Chicago and Buffalo, and which consists almost wholly of a coastwise trade within the confines of the Great Lakes, compares favorably with the tonnage movement of the greater maritime cities of the world.

The vessels engaged in this lake traffic can be divided as regards their work into four principal classes, and may be described as follows:

First and most important are the ore, grain, and coal carriers; second, package, freight, coal, and grain; third, lumber and coal; fourth, passengers and miscellaneous freight. With reference to the method of propulsion, these classes include single- and twin-screw steamers, paddle steamers, and steam, sail, and towing barges. They will be described in their respective order and in a general way.

The first class, as mentioned above, to be described, includes the ore and grain carriers. These are screw steamers of 1600 to 3600 tons burthen and are from 250 to 350 feet in length, with a beam of 36 to 45 feet, and a depth of hold from 18 to 26 feet; with 500 H.P. in the smallest to 3000 in the largest, and a regular sea speed, when running alone, from 10 to 16 miles per hour, and a coal consumption of 1000 to 6000 lbs. per hour.

They are usually two-decked vessels and are built of wood, iron, or steel. They have very little dead-rise and short turned bilges. The lines are full, having a coefficient of .78 to .86, and they are slightly rounded on the side and

with but little tumble-home. The rig usually consists of two, three, or four spars, with top-mast, fore and aft, and jib sails, but at the present time there is a strong tendency to reduce this rig to two or three pole spars without canvas. In fact, nearly all of the modern ships of this class are so rigged.

The propelling machinery is located well aft, with boilers on the main-deck forward of the engines. The deck-house on the spar-deck over the machinery space extends aft, forming the dining-room, kitchen, and pantry, with room for the engineers, cook, and firemen, as well as stores for the engineer's and steward's departments. The rest of the crew are usually berthed on the spar-deck forward of the fore hatch, with room for the captain, first and second mates, wheelmen, watchmen, and deck-hands; also chart-room and captain's office in the texas abaft the wheel-house.

Thus it will be seen that all of the deck forward of the boiler-house to the after side of the forward deck-house is left clear for the loading and unloading of cargo. The hatches are spaced 24 ft. from centre to centre, 6 to 8 feet wide fore and aft, and 20 to 28 feet in width athwartships on the spar-deck, and 6 to 8 feet less athwartships on the main-deck. The coal-bunkers are on the main-deck, forward of the boiler-house, between the hatches and side of ship.

The propelling engines of this class of vessels are of the high-pressure, the condensing, the compound, and the triple-expansion types. The high-pressure engines are built with a single crank. The condensing engines are single and double, with the air, feed, bilge, and cold-water pumps worked by beams and links from the cross-heads of the main engines. The compound engines are built with the cylinders side by side, or on the steeple plan, usually the former, with cranks at an angle of 90° to each other, although in a number of cases the cranks are placed at an angle of 180° for the balance effect. All of the pumps are worked from one of the cross-heads of the main engines. The triple-expansion engines all have the cylinders side by side with the cranks at an angle of 120°, and all of the pumps worked from the main engine in the usual way. All of the engines as above described are of the vertical, inverted, overhead-cylinder type and jet condensing; but in a number of cases lately the air-pumps and condensers are

separate from the main engines, and the former are usually of the horizontal duplex and single-cylinder patterns.

The boilers to supply steam to the high-pressure and condensing engines, as well as some of the compounds, are of the return-tubular, fire-box type, built of steel, for a working pressure of 60 to 120 pounds. These boilers are usually made with two furnaces and water bottom. The boilers that are used with some of the compound and all of the triple-expansion engines are of the Scotch type and are built to withstand a working pressure of 120 to 170 pounds of steam.

All or nearly all of the vessels of this class are equipped with steam capstan-windlasses forward, steam capstan aft, and steam steering gear, located either on the spar or the main deck directly under the pilot-house.

The foregoing description gives an idea of the average vessel of the class engaged in the ore, grain, and coal traffic, but a more complete description with drawings will be given later on of the modern ore-carriers.

The second class of vessels to be described includes those engaged in the package-freight, coal, and grain traffic, which are somewhat similar to the ore-carriers already described, with some additions. Gangways or cargo-ports are cut between the main and spar decks that admit of taking cargoes from the dock directly on the main deck and lowering them into the hold. The lowering of the cargo into the hold is accomplished very rapidly by what is termed "striking-down winches," which consist of a double-geared drum and brake-wheel, located between two stanchions on the forward side of the hatch between decks, with properly-adjusted rope slings wound on the drum. As the load strikes the lower deck, it lifts the upper load clear of the hatch-coamings on the main deck and ready to lower away, the drum being under control by the brake lever.

The machinery for unloading consists of a line of shafting, running fore and aft under the spar-deck and as near the centre of the ship as it can be located, which is driven direct by a vertical, high-pressure engine, placed at the after end of the hold just forward of the boilers. The line-shaft drives by friction two drums at each hatch, one on each side of the line-shaft. These drums are controlled independently of each other, and in hoisting, when the load is lifted clear of the

main hatch-coamings, the friction-wheel on the drum-shaft is forced out of contact by the hand levers against a stationary brake-block, and the load lowered to the main-deck or into the hold, as the case may be. The packages are taken to and from the hatches by stevedores through the gangways or cargo ports at the ship's sides.

The dock-plan and arrangement of machinery and crew space of this second class of vessels are very similar to those of the first class, with the exception of the modern package-freight carrier, which will be described later on.

The third class of vessels comprises those engaged in the lumber traffic. These vessels are small, single-decked, screw steamers, having a length of 150 to 250 feet on the keel, with a breadth of beam from 30 to 45 feet, and depth of hold from 12 to 16 feet. These vessels, with but one or two exceptions, are built of wood, with the machinery well aft and boiler on deck forward of the engine. Accommodations for the crew are provided forward and aft. There are one or two spars with fore-and-aft sails, and when fully loaded to the top of the deck-house, they have but little free-board.

The engines are high-pressure, steeple, compound, and fore-and-aft compound, and are supplied with steam from return-tubular fire-box boilers. The latest vessels of this type have steam capstan windlass forward and steer by hand. The coal-bunkers are alongside and forward of the boilers on the deck. These vessels are not noted for speed, but are powerful towers, and usually take in tow four to eight barges loaded, even on deck, with lumber.

The ships of the fourth class are those engaged in the passenger and miscellaneous freight traffic. These are screw steamers (single and twin) and paddle steamers, the twin-screw vessels being the more modern. They are all handsome steamers with elegant fittings.

The largest and finest of the paddle steamers have their routes between ports on Lake Erie and are 286′ 6″ length over all, 40′ 0″ beam, and 70′ 8″ over the guards, with a depth of 14′ 0″ and a gross tonnage of 1023 tons. They have full-length cabins with single and double tiers of state-rooms. On the main-deck, abaft the machinery, are the reception-hall, with the grand stairway to saloon above, as well as the

purser's office and baggage-room, and a large room farther aft, without berths, for the second-class passengers.

All of the main-deck, forward of the machinery, is used for package-freight. There is a steam capstan-windlass forward, a steam capstan aft, and a steam steerer on the main-deck directly under the pilot-house. The dining-room, galley, pantry, etc., are under the main-deck abaft the machinery, while the electric-lighting plant is located forward of the machinery. These vessels are fitted with compound beam-engines and are supplied with steam from Scotch boilers at 120 lbs. pressure. The engines are capable of driving these boats 18 to 20 miles per hour. These steamers are very similar to the Fall River boats and are finely fitted up.

Those of the single-screw vessels engaged in passenger and freight traffic have their routes from lower Lake Erie ports to the upper ports on Lake Superior, stopping at way-ports on Lake Erie, the Detroit and St. Clair rivers, Lake Huron, Mackinaw, St. Marie, Duluth, and Superior City on Lake Superior. With but few exceptions, the steamers of this class are of wood and are about 225 feet on the keel, 36 feet beam, and 16 feet depth of hold. They are built with two decks and full-length cabins on the upper-deck, and on the main-deck are located the offices, with room for steerage passengers and package-freight. The propelling machinery of these steamers is a vertical, condensing, steeple or receiver compound engine, supplied with steam from return-tubular fire-box boilers. They have a windlass, a capstan, etc., and steer by hand. The speed is about 12 miles per hour.

The twin-screw steamers of this class, engaged in the passenger and freight traffic, are the more modern vessels, built of steel throughout, with water-tight bulkheads and water ballast. They are without guards and have full-length cabin and promenade on cabin-deck. These vessels are fitted with triple-expansion engines and Scotch boilers, with a working pressure of 160 lbs. A steam capstan, a steam capstan-windlass, and a steam steerer are fitted, as well as a complete system of electric lighting and all the modern improvements.

A more complete description of the different types of vessels will be given later, accompanied with plans and sections of hull and machinery.

This ends a brief description of the different classes of the

more important steam vessels on the Great Lakes, but this does not include all the craft that sail these inland waters by any means, although no attempt will be made to enumerate them, further than to give the proportions of each for the year 1891.

The books of the United States Treasury Department contain the names of 3657 vessels, measuring 1,183,582.55 tons, in the Lake trade. In the classification of this fleet, the Lakes have more steamboats of 1000 to 2500 tons than the combined ownership of this class of vessels in all other sections of the country.

The number of vessels of 1000 to 2500 tons on the Lakes on June 30, 1891, was 310, and their aggregate gross tonnage was 512,787.58. In all other parts of the country, the number of vessels of this class on the same date was 213, and their gross tonnage 319,750.84.

The classification of the entiro Lake fleet is as follows:

Class.	Number.	Tonnage.
Steam vessels	1,631	763,063.32
Sailing vessels	1,226	319,617.61
Canal-boats	731	75,580.50
Barges	69	25,321.12
Total	3,657	1,183,582.55

The tonnage built on the Lakes during the past five years, according to the reports of the United States Commissioner of Navigation, is as follows:

	No. of Boats.	Tonnage.
1887	152	56,488.32
1888	222	101,102.87
1889	225	107,080.30
1890	218	108,515.00
1891	204	111,856.45
Total	1,021	485,042.94

The following comparison of the tonnage passing through the canal at St. Mary's Falls (Sault Sainte Marie) and that through the Suez Canal is highly interesting, as showing the volume of business on the Great Lakes:

Number of boats through St. Mary's Falls Canal in 1890,

228 days of navigation, 10,557; net registered tonnage 8,454,435. Number of boats through Suez Canal in 1890, full year, 3389; net registered tonnage 6,890,014.

Number of boats through St. Mary's Falls Canal in 1891, 225 days of navigation, 10,191; net registered tonnage 8,400,685. Number of boats through Suez Canal in 1891, full year, 4207; net registered tonnage 8,698,777.

Number of boats through St. Mary's Falls Canal in 1892, 233 days of navigation, 12,580; net registered tonnage 10,647,203. Number of boats through Suez Canal during 1892, full year, 3559; net rgisteered tonnage 7,712,028.

The detailed descriptions of vessels of the various classes already enumerated will only include the more important types and those for which complete information was most available. The descriptions do not, nor indeed could they, represent the practice of all the builders on the Great Lakes.

To attempt a description of the practice of every builder of hulls and machinery would entail an enormous amount of labor to secure the necessary data and drawings, and without them a verbal description would be interminable and uninteresting.

This is specially characteristic of the machinery, for almost every builder has his own ideas as to number, proportions, and arrangement of cylinders, type and size of valve-gear, sequence of cranks, etc., etc., through all the details.

For the hulls, typical drawings illustrate the practice of all builders fairly well, with the exception of the whale-backs, which of course are a special type.

Consequently, as has already been said, we shall limit our description to such examples as are most typical and best accommodate themselves to the space allowed in the Proceedings of the Congress.

A detailed description accompanied by drawings in plan and section will now be given, showing the best practice of the ship and engine builders on the Lakes.

Figs. 1 to 10 show midship and longitudinal sections, spar-deck plan, and side elevation of vessel, cross-sections through engine and boiler spaces respectively, of a modern, steel, ore and grain carrier. This is a vessel built of steel throughout, 348 feet over all, 330 ft. keel, 45 ft. beam moulded, and a moulded depth of 24 ft. 6 in. The lines are very full with a

coefficient of .82. As will be seen from the midship section, the vessel has but little dead rise, only three inches, and a sharp turn of bilge, six inches of a tumble-home, and slightly rounded on the side.

These vessels are built with a flat-plate keel and deep main keelson, 54 inches in depth, and side-plate keelsons on top of floors, spaced and arranged as shown. These are 5 feet 4 inches from centre to centre, from the middle line out, and are covered with a steel deck, thus forming a double bottom as well as a ballast tank. The double bottom extends from the collision-bulkhead forward to the bulkhead at forward end of stern-tube, and is divided longitudinally by the main keelson and transversely by five solid floors, thus making seven water-tight compartments. That under the engine is divided water-tight longitudinally.

The total capacity for water ballast is 1100 tons. These compartments have a complete system of pipes for filling and discharging the water ballast, controlled from the engine-room, which is accomplished by connections being made from the sea-cock, and a ballast-pump to the distributing valve-box connecting to the pipes leading from the different water-tight compartments.

It will be seen from the midship section that these vessels have two decks. The spar deck is of steel and not covered with wood. The main-deck is of pine 3½ in. thick laid over the stringers and tie-plates. The tank-top is stiffened by Z bars on every other frame-space, and covered with one inch of pine and two inches of oak above the upper turn of the bilge. The midship section also shows how the tank top connects to the hull plating at the margin, and all particulars are enumerated, such as scantlings, equipment, spacing of frames, beams, reverse-frames, web-frames, deck-stringers, tie-plates, etc.

The longitudinal section shows the division of the machinery space and cargo holds; also number and arrangement of cargo and coaling hatches. It will be seen that as much space as possible is devoted to the handling of cargo. The importance of this will be seen when the fact is stated that the entire load of ore, amounting to 4260 gross tons, has been taken out in 10 hours. These cargo hatches, which are nine in number, are spaced 24 feet from centre to centre, excepting

one space forward which is 36 feet, thus made to accommodate the cabins. All of the cargo hatches on the spar-deck are 8 feet wide fore and aft by 32 feet athwartships, and those on the main-deck are 8 by 24 feet. The cargo-holds are in three separate compartments, from the collision-bulkhead forward to the bulkhead forward of the engines, being divided by two water-tight bulkheads to the main-deck.

The boilers are placed on a separate deck, 4 ft. 6 in. lower than the main-deck, and the cargo is trimmed 24 feet back under the boilers to the engine bulkhead. The coal-bunkers are forward of the boilers on the main-deck, and occupy the space between the hatches fore and aft and along the ship's side as well. The coal for fuel is taken on board from coaling scows having a travelling steam-derrick. The coal runs into the bunkers and requires very little trimming, and is accomplished while the vessel is being unloaded.

These vessels are built with open stern-frames that admit of a balanced rudder as shown on the longitudinal section, the shoe being forged solid with the frame. The weight of the rudder is taken on the spar-deck by clamp-collars and bearing-plate. The lower end is steadied by a pintle on the rudder fitting into the shoe. The rudder-stock is fitted with a quadrant under the spar-deck and swings aft. The quadrant is grooved for one inch chain.

The chain from the quadrant leads to quarter blocks at the ship's side and forward to the traveller-block of a three-fold purchase. This purchase is fitted with ⅝ chain for the running part, and connects to one-inch-diameter wire rope for the standing part that leads forward under the spar-deck to the quarter blocks abreast of the steam steerer. These quarter blocks abreast of the steerer, and the steerer drum as well, are grooved for ⅝ chain, which connects to the wire rope and leads through the block and over a double chain-sheave to the steerer drum. The port wheel-chain occupies one half and the starboard chain the other half of the steerer drum. The standing part or wire rope is run through fair leaders bolted to the spar-deck beams.

As will be seen from the longitudinal section of vessel, the steam steerer is placed on the main-deck below the pilot-house, and connects to the steering-wheels on the wheel-stand by a vertical shaft and mitre gears. Either wheel is used to

steer the ship, as they are always in gear with the vertical shaft which operates a hunting-screw on the steam steerer. This hunting-screw is connected to the change valve on the steerer by bell-cranks. The steerer can be changed from steam to hand and *vice versa* by two shifting rods from the steerer to the stand in the pilot-house within easy reach of the wheelman, and the changing from steam to hand power can be very quickly done without any danger of fouling or blocking the steerer.

The longitudinal section shows the location of the steam capstan-windlass under the forecastle deck. The windlass is a combined steam and hand power machine and steam reversible. The capstan can be disconnected. All of the lines for breasting in and warping the vessel are taken in through line chocks abreast of the windlass and through leading chocks to the winch-heads on the windlass-shaft.

The anchors are carried on the forecastle deck, one on each side of the stem, and are handled by an anchor-davit stepped just abaft the stem, and with block and falls on the davit; the anchors are handled very quickly. Amidships on the spar-deck is placed a steam winch to be used to assist in handling the vessel at the dock, to hoist stores aboard, etc.

Below the spar-deck, just forward of the rudder-post, is placed a reversible steam capstan for handling the stern lines, besides being used as an auxiliary steering gear. This is accomplished by two pairs of blocks and falls hooked to a spare tiller, which is always kept shipped in place on head of the rudder-stock, and the other end of the fall shackled to stanchion on each quarter. The lines being taken to the capstan, and with a couple of turns around the barrel, the reversing lever being above the deck, a very efficient steam steerer is made available.

These vessels have two small pole-spars without any canvas. The spars are of pine and are stepped on the main deck. All of the rigging is of steel-wire rope set up with turnbuckles. The hatch-coamings are made of 10 in. bulb beams, and the hatch-covers are made in sections of 2-in. matched pine, well battened, and have canvas covers when at sea in rough weather, all battened down by long oak battens athwartships. From the deck plans it will be seen how the

crew are berthed, also the general arrangement of dining-room, pantry, galley, lavatory, etc.

These vessels are fitted with vertical, triple-expansion, jet-condensing engines of 2163 indicated horse-power. The diameters of cylinders are 24 inches high, 39 inches intermediate, and 63 inches low pressure, by 48 in. stroke. The high-pressure cylinder is fitted with a piston-valve, while there is a single-ported slide on intermediate and a double-ported slide on the low-pressure. All of the valves are driven by double-bar links and eccentrics, and are reversed by combined steam and hydraulic gear.

The cylinders are arranged with the high-pressure forward and followed by intermediate and low-pressure cylinders. It will be seen from Figs. 7 and 8 that the valve-chests for the high and intermediate cylinders face each other, with the exhaust cavity of the high-pressure valve in direct communication with the valve-chest of the intermediate. The valve-chest of the low-pressure cylinder is between the intermediate and low, and the exhaust from the former to the latter is by a belt around the intermediate cylinder. The joints between the cylinders are scraped and ground, and all of the holes for the joint bolts are reamed and fitted with turned bolts.

It will be seen from the drawings that the front and back columns are alike, that is, they are forked and of box section. Those on the back have faces to which are bolted the air-pump and condensers, the middle one taking the bearing for the air-pump beam.

Distance-pieces are fitted between the columns midway of their length and all secured by through-bolts. The cross-head guides are cast separate from the columns, and are of cast-iron, planed and fitted in place. All of the pistons are of cast-iron, fitted with followers and single narrow ring and break joint. The rings are set out to the walls of the cylinder by flat bent springs.

The piston-rods are of steel and extend through the top heads; the rods are fitted into the piston and cross-head taper and secured by nuts. The cross-heads are of forged iron with turned gudgeons for the forked end of the connecting-rod. The guide-shoes of the cross-head are of cast-iron lined with genuine babbitt metal. The valve-stems are of steel and secured to the valves by steel plates and keys; the

lower end is bored out to receive the link-block and fitted with strap and bolts. The connecting-rods are of reforged scrap-iron; the upper end is forked and fitted with T-end brasses and bolts; the lower end is forged solid, bored out, and fitted with brasses lined with genuine babbitt metal and secured by cap and bolts.

All of the cylinders are provided with relief-valves, top and bottom, and in first and second receiver-space. Arrangements are made for varying the cut-off by slotted reverse-arms fitted with block and adjusting screw.

The air-pump, two feed and cold-water and one bilge pump are worked off the middle engine by beams and drag link in the usual way, the condenser and air-pump being connected by pipe channel. The air-pump is fitted with circular rubber valves working on studs fitted with flat guards and nuts; the foot and discharge valve-seats and the bucket-valve are of brass; the bucket is fitted to the pump-barrel without junk ring or packing, but water-grooved. All of the valves are made accessible by man- and hand-hole plates. The feed-pump valves are of brass working in brass seats in the usual way; those of the cold-water and bilge pumps are flat circular disks of rubber. The condenser is cone-shaped and fitted with adjustable spray-nozzle and cone spray-plate, also injection-valve worked from the starting platform.

The cranks are of forged iron built up in three interchangeable parts with solid flange couplings, fitted with turned bolts. The cranks are arranged in the following order: low, intermediate, and high. The main journals in the bed-plate are bored out and fitted with brass bushes lined with babbitt metal. The thrust-block is of the horseshoe type; the shoes are faced with babbitt metal and all are fitted in a sole-plate of box section and bolted to the after side of bed-plate.

As the engine is placed so far aft in the vessel, the shafts are very short, and in this case only two lengths of shaft are required, the thrust and tail shafts. These shafts are of forged iron coupled by solid flanged couplings and turned bolts. The after end of the tail shaft, where it fits in the stern-bush, is covered with brass. The stern-bush is also of brass and in two parts fitted with lignum vitæ and secured in the stern-tube by a flange and screws to the nut, locking the tube to the stern-post; and the tube, at the forward end, is secured to the

bulkhead by a flange on the tube and wood backing and through bolts. The forward end of the tube is fitted with stuffing-box and gland in the usual way.

The propeller is a four-bladed sectional wheel, of a modified Griffith form, trailing slightly, having a diameter of 14 feet 6 inches, a pitch of 20 feet, and an expanded surface of 76 square feet. The wheel is fitted to the tail-shaft on a taper the length of the boss, and is secured in place by spline and nut on the after end.

All of the levers used to work the engines are brought down and grouped at a convenient point on the engine within reach of the starting platform. It may be said in passing that the cylinders are not steam-jacketed. The piping is of wrought-iron with screwed fittings, except the main steam-pipe, which is of wrought tubing with riveted flanges. Slip-joints are provided in the cross and main steam-pipes. Gratings and ladders are provided to make all parts accessible. Ash-chutes fitted with water-tight doors are located in the stoke-holds, one on each side of the ship, above the main-deck, within easy reach of the stoke-hold floor, thus enabling the fireman to throw the ashes overboard direct.

In addition to the two feed-pumps worked from the main engine, there is one 8″ and 4″ by 10″ duplex donkey-pump and one injector. All of the pumps are connected to feed the boilers from the hot-well or from the sea. The engines are usually worked with 22 inches of vacuum and a temperature of 135° in the hot-well. A worm and gear operated by hand is provided to turn the engine when adjusting.

It will be seen from the drawings of the boilers, Figs. 9 and 10, that they are of the Scotch type, three in number, of steel and built to withstand a working pressure of 175 lbs. per square inch.

The boilers are 12 feet in diameter by 12 feet long, having three furnaces in each. The furnaces are 38 inches in diameter, plain and stiffened by Adamson joints. Each furnace has a separate combustion-chamber. There are 188 tubes, 3½ inches in external diameter, 144 of which are plain and 44 stay-tubes. The stay-tubes are screwed into front and back heads, expanded and then beaded. All of the stay-bolts are screwed and riveted. The through-braces in the steam space are of

B.B. iron 2⅝ inches diameter, upset to 3 inches at the end and secured in the heads by double nuts.

The longitudinal seams are double butt-strapped and treble riveted; all of the other outside joints are lapped and double-riveted. The plate edges are planed and calked on the outside. There are 1854 square feet of heating surface and 61 square feet of grate surface in each boiler; ratio of heating to grate surface 30 to 1. The uptake is common to the three boilers and is lined up to the funnel-base. The funnel is 41 feet above the level of the grates and is not lined.

These vessels carry a crew of 23 men, captain, two mates, two wheelmen, two watchmen, six deck-hands, two engineers, two oilers, four firemen, one steward, and one assistant steward; they have a regular speed of 13 miles an hour.

The next on the list to be described are those vessels engaged in the package-freight, coal, and grain traffic.

Figures 11 to 20 show midship and longitudinal sections, spar-deck plan and side elevation of hull, cross-section through engine and boiler space, and side and end elevation of engine respectively, of a vessel 306 feet over all, 290 feet keel, 40 feet beam moulded, and 25 feet moulded depth. These vessels are built of steel, having fair lines, with a coefficient of .76. It will be seen from the midship section that there is but nine inches dead rise, a tumble-home of ten inches, and short-turned bilges. These vessels have a plate keel and deep main keelsons similar to the vessel just described, except in this case the keelson is 42 inches deep. The side keelsons are run through continuously over the top of the floors.

The keelson midway of the half breadth is intercostal between the floors and connected to the outside plating as shown on the midship section. A steel deck is laid over the keelson, thus forming the double bottom and ballast tanks; and the compartment for water ballast extends from the collision-bulkhead forward and through the machinery space to the stuffing-box bulkhead. It is divided longitudinally by the main keelson, and transversely by the solid floors, thus forming eight water-tight compartments that have a total capacity for water ballast of 750 tons. All of these compartments have the same system of valve-boxes and pipes, for filling and discharging, as that described for the ore-carriers.

This vessel has two steel decks, the spar-deck being overlaid with $3\frac{1}{2}$ inches of pine.

The longitudinal section shows the arrangement of cargo and machinery holds, also hatches and side ports. The hold is divided by four water-tight bulkheads to the main-deck (the collision bulkhead extending to the spar-deck). There are six cargo-hatches, 8 feet fore and aft by 20 feet athwartships on the spar-deck and 14 feet athwartships on the main-deck. There is one coaling-hatch forward of the boilers. The lower hold has an extra tier of beams. Cargo-battens are fitted along the sides in lower cargo-holds and 'tween decks. The tank top is protected by being sheathed with an inch of pine and two inches of oak bolted to the stiffening angles. It will be seen from the longitudinal section that the machinery is well amidships, and in this case the boilers are in the lower hold.

The coal-bunkers are forward of the boilers, and these vessels can be coaled with but little trimming. The stern-frame is forged solid with shoe and rudder-post and bosses to receive the rudder pintles; therefore the rudder is without balance and the weight is taken on the spar-deck by clamp-collars and bearing-plate and is further supported by the pintles fitting in the post and shoe. A quadrant is fitted to the rudder-stock below the spar-deck, which is grooved to receive two parts of one-inch chain, one leading to port and the other to starboard, and through quarter-blocks at ship's side, fitted with 24-inch-diameter sheaves with metalline bushes. The chains connect with $1\frac{1}{4}$-inch-diameter wire rope which runs forward under the spar-deck beams abreast of the steam steerer, where they connect to $\frac{7}{8}$-inch chain on the steerer drum. The $\frac{7}{8}$-inch chain is of sufficient length to let the wire rope clear the quarter-blocks, which are fitted with 24-inch-diameter sheaves similar to those aft. In this case the steam steerer is located on the spar-deck directly under the pilot-house and connects to the wheel-stands and wheels by an upright shaft and bevel gears, for the hand steering, and by a rod from the trick-wheel to the middle valve on the steerer; additional hand steering is provided aft, which consists of a right- and a left-hand screw and arms on the rudder-head.

The vessel is provided with steam capstan aft and steam capstan-windlass forward under the forecastle deck; also four steam cargo-winches, two double and two single. These

winches, in connection with the boom derricks, handle the cargo over the rail or on the main-deck through the side ports, and in addition to the above each hatch is provided with the double-geared "striking-down winches" already described. These vessels have four pole-spars, three of pine and one of steel. The deck-plan shows the cabin arrangements.

These vessels are fitted with triple-expansion engines of 1800 indicated horse-power. The engines are vertical and jet-condensing, having a 24-inch high-, 38-inch intermediate-, and 61-inch low-pressure cylinder by 42 inches stroke and arranged with the high-pressure cylinder forward. A single-ported slide-valve on the high-, a single-ported slide-valve on the intermediate-, and a double-ported slide-valve on the low-pressure cylinder are operated by double-bar links and eccentrics and reversed direct by steam. The cutting off is effected by hooking up chocks engaging trunnions on the cross-head of the steam reversing engine, which admit of a cut-off at 23 inches.

The cylinders are bolted together, forming the valve-chests for the intermediate- and low-pressure valves. The joints are scraped and ground and fitted with turned bolts. All of the levers for handling the engines are grouped together at a convenient point on the engines and within reach of the working platform. The pistons are of cast-iron fitted with a narrow ring set out by flat bent springs. Steel piston-rods are used; that of the low-pressure works through the top head. The rods are secured in the pistons and cross-heads by taper and nuts.

The connecting-rods are of the best forged scrap-iron, forked at the top and fitted with adjustable brasses and bolts, the lower end fitted with brass bushes lined with white metal and made adjustable by bolts and nuts. The cranks are of forged wrought scrap, built up in three interchangeable parts, connected by solid forged couplings and turned bolts, and are set at an angle of 120 degrees in the following sequence: low, intermediate, and high.

The thrust-block has white-metal bearings, and the driving and backing faces are of brass, made adjustable by liners. The collars on the shaft are of hard cast-iron clamped to the shaft. The sole-plate of the thrust-block is bolted to plate and angle work built up from the deck, and the thrust-block is adjustable on the sole-plate by wedges and bolts. The

main journals in the bed-plate are fitted with square brasses that are bored to receive the crank-shaft. The front and back columns are alike, single, of box section, and fitted with water-back guide-plates. The cross-head shoes are faced with adjustable brass faces. The valve-stems are of steel and the lower end fitted to receive the link-block. A worm and gear are provided to turn the engine by hand.

The air-pump and jet condensers as well as the feed, bilge and cold-water pumps are attached to the main engine. The ballast-pump is of the duplex pattern. The entire shafting is of wrought scrap with forged couplings bolted with turned bolts. The outer end of tail-shaft where it works in the stern-bush is covered with brass; the stern-bush is of the same metal lined with lignum vitæ. The bush is secured in the stern-tube by a flange and slot-head screws to the locking nut on the after side of the stern-post.

The propeller wheel is a four-bladed, sectional, true screw, and the form a modified Griffith; it is 14 feet in diameter, with a pitch of 17 feet 6 inches and a total blade surface of 70 square feet. The wheel-boss is fitted taper on the shaft and is secured by a spline and nut.

The boilers are of the Scotch type, 11 ft. 10 in. diameter by 12 feet long, having three corrugated furnaces 36 inches diameter inside the corrugations. The combustion-chamber is common to the three furnaces. The tubes are plain and expanded in each tube-sheet. The total heating surface in the three boilers is 5574 sq. ft. and the grate surface 162 sq. ft. The ratio of heating to grate surface is 34.4 to 1. The boilers are set on cast iron saddles, and the three boilers are connected to the horizontal steam-drum. The drawing shows how the connections are made. Slip joints are provided in the cross and main steam-pipes; all of the piping is of wrought-iron with screwed fittings.

The grate-bars used are of the Ætna pattern and are 6 feet in length. There is a small donkey boiler on the spar-deck inside the boiler-trunk and piped into the large funnel. The uptake is common to the three boilers and is double up to the funnel base, the funnel not being lined. The ashes are hoisted to the spar-deck by a small steam ash-hoist bolted to the bulkhead.

The exhaust steam from all of the auxiliaries passes

through a heater, through which the feed-water is pumped to the boilers.

It will be seen from the side elevation that the pilot-house is well amidships, and the machinery as well, making this class of vessels easy to trim and handle. Regular speed fourteen miles per hour.

Of that class of vessels engaged in the passenger and freight traffic, those of the twin-screw class are the latest type of the modern fast passenger service on the Lakes. The vessel to be described is a ship 278 feet over all, 260-foot keel by 38-foot beam and 25-foot depth moulded; fine lines having a coefficient of .64, and a tonnage of 1762. Figures 21 to 30 show midship section, spar- and main-deck plans and elevation, cross-section through engine and boiler spaces, longitudinal section and plan of general arrangement of machinery, and side and end elevation of engine.

It will be seen from the midship section that this vessel is somewhat similar, as regards keel-plates, floor-plates, main and side keelsons, tank-top, etc., to those vessels already described.

The double bottom is 42 inches deep and extends from the collision-bulkhead forward to the stuffing-box-bulkhead aft and has an actual capacity for water ballast of 500 tons. There is a small tank built on top of the floors abaft the engines to receive the drainage from the tank-top in the engine-room; there is a larger one under the galley to supply the vessel with clean water while in port. There are six bulkheads built up to the main-deck, three of them water-tight, while the collision-bulkhead is extended to the spar-deck. The compartments in the double bottom have a complete system of piping, for filling and discharging, similar to those vessels already described.

The main- and spar-deck plans and cross-sections show that the cabins are built the full length of the vessel, with a single tier of state-rooms and saloon the length of the cabin. A feature peculiar to this vessel is that each state-room is fitted with a portable set of berths which can be drawn out into the saloon and in no way disturb the occupants of the state-room. This is accomplished by a false panel opposite the berth of each state-room; the berths are attached to the false panel together with the curtain-rods, and being mounted

on casters are easily drawn out. There are sleeping accommodations for 268 people, and the dining-room has a seating capacity for 110. It will be seen from the plans that the dining-room, pantry, and galley are below the main-deck, forward of the boilers, and are accessible by stairway at the forward end of the saloon. The cabins are finished in mahogany and lincrusta-walton; the dining-room in white and gold. The entrance to the saloon is from the "social hall" abaft the machinery, where all of the officers are located. The social hall is vestibuled off from the gangways, thus giving room to shut the gangway, handle lines, etc. All of the main-deck forward of the boilers, and on each side of the boiler-trunk back to the engine-hatch, is used for stowing freight.

The coal-bunkers extend across the vessel, forward and aft of the boiler, and the coal is run through scuttles on the main-deck. It will be seen from the cross-section that the cabin is built with a transom skylight, and the cabin-deck is used as a promenade and is provided with awnings the entire length of the deck. A complete system of water-works supplies the state-room lavatories, galley, etc., with water, and a complete system of drainage is provided from the state-rooms and lavatories as well.

The vessel is fitted with two complete systems of electric lighting of 450 lights each, besides electric side and mast-head lights. There is a steam capstan aft, a steam capstan-windlass forward, and a steam steerer on main-deck below the pilot-house. The pilot-house is large and roomy, and directly back of it are the two observation-rooms, one for ladies and the other for gentlemen's smoking-room. On the bridge are placed two of Chadburn's engine-room telegraphs. The midship section gives the scantlings and equipment. The side elevation of the vessel shows that the rig consists of two pole-spars with standing gaffs. The spars are of steel and have steel-wire rigging, set up with turnbuckles.

These vessels are fitted with vertical triple-expansion, jet-condensing engines of 1300 indicated horse-power each. The sizes of the cylinders are 20-inch high-, 32-inch intermediate-, and 52-inch low-pressure by 36-inch stroke. The high-pressure cylinder is fitted with a piston-valve, the intermediates with a single-ported slide-valve, and the low-pressure with a double-ported slide-valve, all being operated by double-bar

links and eccentrics, and reversed direct by steam. The pistons are of cast-iron with a single ring in each, set out by flat bentsprings. The piston-rods and valve-stems are of steel. The piston-rods are secured to the pistons and cross-heads by taper and nuts. The engine columns are of cast-iron, front and back, of box section fitted with cast iron guide-plates; the guide-plates on the driving side have water-back. The connecting-rods are of forged scrap iron forked at the top and fitted with adjustable brasses and bolts; the lower end worked out of the solid and fitted with brass bushes lined with white metal and adjustable by bolts.

The crank-shafts are similar to those described, built up and interchangeable, with solid forged coupling and turned bolts; the cranks are at an angle of 120 degrees and in the sequence low, intermediate, and high. The main journals in the bed plate, which are six in number, are fitted with brasses let in square and are not lined. The sole-plate for the thrust-block is bolted to the bed-plate; the block is adjustable on the sole-plate by wedges, and is bored and fitted with brass-flanged bushes for the bearing and thrust faces. The collars of the shaft are of hard cast-iron in halves and bolted to the shaft. The working platform is located between the engines, and all of the levers for operating the engines are grouped on a convenient part of the engine framing. The Chadburn duplex telegraph communicating with the pilot-house is placed within easy reach from the working floor. All of the pumps are detached from the main engine. The air-pump is jet-condensing, horizontal, duplex, and all of the feed, bilge, and cold-water pumps are of the duplex pattern, as well as the ballast and water-service pumps.

The engines turn outboard, with right- and left-handed true-screw wheels, 11 feet diameter by 15 feet pitch. Each wheel has an expanded surface of 45 square feet, and the shape is a modified Griffith. The wheels work opposite each other and abreast of an opening in the stem of the vessel between the stern-post and rudder. The stern-post is open, that is, without any rudder-post. The rudder is supported by the shoe, which is forged solid with the stern-post. The rudder is formed with a counterbalance, and the entire weight of the rudder is taken on the spar-deck by plate and clamp collars as in the vessels already described.

The outer end of the tail-shafts is supported by cast-steel A frames bolted to the stern-post. The bearings in the boss of the A frames are of composition in two parts, fitted with lignum vitæ, and the after end of the stern-tube is fitted in a similar manner. The forward side of the bosses on the A frames is made cone-shaped by bolting on a light casting, and the outboard coupling in the shaft abaft the stern-tube is protected in the same way. All of the line-shafting is of the best forged scrap-iron, with solid forged couplings and turned bolts. The tail and outboard shafts, where they work in the lignum vitæ bearings, are covered with composition sleeves.

Steam is generated for these engines in two double-ended boilers of the Scotch type, built to stand a working pressure of 160 lbs. per square inch. These boilers are 13 ft. in diameter by 21 ft. 2 in. long, and the shell is of $1\frac{1}{16}$-in. steel. There are six furnaces in each boiler, 40 in. in diameter, stiffened by Adamson rings. The combustion-chamber is common to all the furnaces. Total heating surface in each boiler 3654 sq. ft. and total grate 120 sq. ft. Ratio of heating to grate surface 30.4 to 1.

It will be seen from the longitudinal section that there is but one funnel, with the uptake arched over the top of the boilers and double at the base of funnel. There are two large steam fans on the level of the main-deck in each stoke-hold; they are forward of the engines and draw the air out of the engine-room and deliver it in the fire-room. The one forward of the boiler can draw the air either from the galley, pantry, or dining-room or from one of the downtakes and discharge into the fire-room. There is a vertical donkey boiler in the forward hold for cleaning out and pumping up the main boilers.

The electric-light plant consists of two Beck automatic engines coupled to two Mather generators of 450 lights each. The coal-bunkers have a capacity for 150 tons of coal. The vessel has a regular speed of 16 miles an hour and requires a crew of 65 men.

Before passing the subject of twin-screw vessels, a description of the new twin-screw express steamers, now building for fast passenger service on the Lakes, together with plans, sections, and elevations of vessels and machinery, will not be

deemed out of place here. These are steel steamers designed for fast passenger service between Buffalo and Duluth in connection with the Great Northern Railway. They are for passenger service exclusively, as they do not carry any freight, and are to be fitted with all the modern improvements that can be suggested.

The dimensions are 383 ft. over all, 360 ft. keel, 44 ft. beam, and 26 ft. deep. The lines are fine, giving a coefficient of .62. Displacement 2200 tons at 14 ft. draught. Figures 31 to 38 show midship section, hurricane-, spar-, main-, and lower-deck plans, and side elevation of vessel; also front and side elevation of engines and hull respectively. From the midship section it will be seen that the construction is somewhat similar to the vessels already described; but in this case the dead rise is 15 in. and tumble-home 13 in.; the main keelson is 42 in. deep on top of a flat plate keel and continuous liners; the side keelsons on top of floors are spaced 4 ft. 9 in. centres, the middle one being intercostal between the floors and lugged to the shell plating. A steel deck is laid over the keelson and stiffened by Z bars. The tank-top is decked over on top of the Z bars and to the upper turn of the bilge with 2½ in. of oak.

An orlop deck extends from the bulkhead forward of the boiler to the collision bulkhead, and the deck-room is used for the emigrants. From the bulkhead abaft the engines an orlop deck extends aft to the stern-tube bulkhead, and the space is to be used for a baggage-room. The main-deck is of pine 3½ in. thick; spar-deck of steel overlaid with pine 2½ in. thick.

The main-deck and the hold-stringers connect to the shell plating. The ballast-tanks have a capacity for 750 tons of water. All of the compartments are fitted with a complete system of piping for filling and discharging, the pumps and valve-boxes being located in the engine-room. The hull is constructed with seven athwartship bulkheads, six to the main-deck and one to the spar-deck. The midship section gives all the particulars relating to the scantlings, spacing of frames and deck-beams, belt-frames, equipment, etc.

The cabins have sleeping accommodations for 318 people, and the dining-room has a seating capacity for 102. As indicated, the dining-room is on the main-deck forward of the

boilers, and on each side of the boiler-casings are arranged the pantry, saloon, galley, and store-room, crew and engineers' galley, cooks' and officers' mess-room on one side, and on the other are the officers' and crew's lavatory, deck-hands' and firemen's mess-room, rooms for water-tenders, deck-hands, and firemen; also lavatories for the emigrants. Forward of the dining-room are rooms for mates, wheelmen, watchmen, and lookouts. Abaft the engine-hatch are arranged rooms for engineers, oilers, and clerk's office, facing the vestibule, which is entered from gangways at the ship's side.

From the vestibule the grand stairway leads to the cabin on the spar-deck. Abaft of the vestibule are arranged a bar and smoking-room, stores, etc. The entire spar-deck is used for the first-class passengers, state-rooms, lavatories, and bath-rooms. On the hurricane-deck abaft the funnel-casing are located the ladies' deck saloon and state-rooms, with an opening through the deck for light and air to the cabin below. Forward of the forward funnel-casing is the men's deck sáloon, which is used as a smoking-room and is fitted with state-rooms, lavatory, and bath. The hurricane-deck will serve as the promenade, and the life boats and rafts will be carried up level with the top of the funnel-casings. The coaling-hatches, four in number, are on this deck, and the coaling will be done by steam derricks.

These vessels are fitted with two vertical quadruple-expansion engines of 3500 H. P. each. The sizes of the cylinders are 25 in. for the high, 36 in. for the first intermediate-, 51½ in. for the second intermediate-, and 74 in. for the low-pressure, with a stroke of 42 in. Piston-valves are used on all of the cylinders; one for the high-, two for the first intermediate-, two for the second intermediate-, and two for the low-pressure, arranged outboard on the working side. All are operated by the Joy valve-gear and reversed direct by steam and hydraulic gear. The reverse arms are slotted and are fitted with blocks and adjusting screws. The engine-columns on the back or inboard side are of cast-iron, forked, and o box section, and are braced together by cast-iron, flanged distance-pieces. The columns are fitted with detachable, water-back, guide-faces. The front columns are of turned wrought-iron, to which are attached by brackets the reverse shaft and link for the valve-gear. The cylinders are without

jackets or liners, and the valve-chests are connected by faced joints and turned bolts. The L. P. and second I. P. cylinders are fitted with cone-shaped, disk, steel pistons; and the first I. P. and H. P. cylinders have cast-iron pistons, all of which are fitted with followers and single-ring packing set out with flat-bent springs. The piston-rods are of steel, but do not extend through the top cylinder-head, and are secured to the piston-head by quick taper and nut. The lower end is fitted with bolts and brasses that connect to pin in the upper end of connecting-rod.

The cross-head, which is of the slipper pattern, of cast-iron, is fitted with adjustable brasses and bolted to the piston-rod. The connecting-rod is of reforged iron, the lower end T-shaped and fitted with brasses lined with babbitt and secured to the rod by bolts and plate. In the middle of the rod, jaws are forged on and slotted out to receive the brasses, to which is connected the vibrating lever of the valve-gear. The upper end of the rod is forked and fitted with the steel pin that engages the cross-head as already described.

The bed-plate is of cast-iron in four sections planed and bolted. The main journals in the bed-plate are bored out and faced at end; brass bushes without flanges and babbitted are fitted top and bottom alike, and secured in place by cast-iron liners and bolts. The crank-shaft is of wrought-iron built up in four duplicate, interchangeable parts 13½ in. in diameter, and crank-pin 14 in. in diameter by 16 in. long. The crank-shafts have solid forged couplings and fitted, straight, turned bolts. The total bearing in the bed-plate is 10 ft. 8 in. The thrust-block is of the horseshoe type, with cast-iron shoes and faced with babbitt, the sole-plate being bolted to the bed-plate. Intermediate bearings, lined with babbitt metal, are placed at proper intervals to support the intermediate shaft.

The propeller wheels are four-bladed, sectional, 13 ft. in diameter and 18 ft. pitch. The blades are of cast-iron and have an expanded surface of 75 sq. ft. in each wheel. The wheels are right and left, and fitted to the tail-shafts with taper, key, and nut.

The engines are fitted complete with relief-valves at each end of cylinders and in receiver-chests; and drain-valves are fitted to bottom of cylinders and valve-chests, and arranged

to be handled from the working platform. The air-pump and condenser are detached from the main engine, and are of the vertical, compound, and direct-connected type; size of steam cylinders 15 in. high-pressure, 30 in. low-pressure, by a stroke of 18 in. The air-pumps are single-acting, 38 in. bore by 18 in. stroke. The condenser is bolted on the side of the channel-plate, and is fitted with cone and spray nozzle, injection-valve, etc. The feed-pumps will be placed in the fire-room.

The cold-water, bilge, and sanitary pumps are of the vertical, duplex type, and all located in the engine-room. The boilers that are to generate steam for these engines are water-tubular, of the Belleville type, and deliver the steam to the engines at 210 lbs. pressure. There are to be 28 boilers in each ship, arranged in three separate fire-rooms, and, as will be seen from the cross-section, they will occupy the central portion of the vessel, with the stoke-holds and coal-bunkers on the outside; that is, the boilers are placed back to back and are fired athwartships. Steam fans will be placed in each boiler-room to assist the draught and ventilation.

Three complete systems of electric lighting will be employed, and the direct-connected type of generator will be used. Steam steering-gear will be fitted on the main-deck below the pilot-house; steam capstan-windlass on the spar-deck forward, and steam capstan aft.

The longitudinal view shows how the vessel is rigged—two steel pole-spars and standing gaffs, and three funnels. The engines when turning 120 revolutions per minute will indicate 3500 H. P. each, and, with a total horse-power of 7000, the vessel is expected to make a regular speed of twenty statute miles per hour.

The coal-bunkers have a capacity of 800 tons of coal, and the vessel will require a crew of 137 men.

The next on the list to be described are the paddle steamers that are engaged in the passenger and freight traffic, and the most notable of this class are shown in Figures 39 to 44, which show midship section, orlop, main-saloon, and gallery decks and longitudinal elevation, respectively, of a paddle steamer 294 ft. over all, 284 ft. length of keel, 40 ft. beam moulded, 70 ft. beam over guards, and 16 ft. moulded depth, with a displacement of 2250 tons at load draught. The main-

hold is divided by seven water-tight bulkheads extending up the main deck.

It will be seen from the midship section that the vessel is built with sponsons and a double tier of state-rooms in height, and on outside a row of state-rooms as well. The vessel is built with 18 in. dead rise, large turn of bilge, and flat keel-plate, with main keelson 36 in. deep; floors 24 in. deep and side keelson on top of floors; double angle-bar stringers at the bilge, and the same half way above the turn of bilge. Abreast the paddle-wheel the sides are stiffened by belt-frames and stringer-plates. The deck is 4-in. pine laid over the deck-beams and tie-plates, and 3½-in. pine over the sponsons. The opening in the sponson deck outside of the paddle-wheel is protected by heavy oak timbers, 14 in. deep by 49½ in. wide, which form the support for the eccentric bracket; an oak rubbing-piece faced with steel is worked around the outside. The sponson deck is supported by 4 × 4-in. angle-braces on every frame-space, and the under side of sponson deck is protected by 2 × 4-in. oak battens bolted to the under side of the beams.

The saloon deck is ⅞-in. matched pine, and 2¾ × 4¾-in. pine carlings spaced 24 in. centres; also the gallery and promenade decks are ¾-in. matched pine on top of 1¾ × 3¾-in. pine carlings spaced 19½ in.; that of the promenade deck being overlaid with canvas and white lead. A transom sky-light is built the length of the gallery-deck. The cabins on the gallery-deck are finished in white and gold, while the main-saloon is in mahogany and lincrusta-walton. The cabins have 120 state-rooms, or sleeping accommodations for about 300 passengers.

The social hall, which is a feature of these steamers, is located on the main-deck abaft the engine-casing. Large sliding doors at each side of the hall, abreast of the gang-ways, are provided for the entrance to the grand stairway to the saloon above. Adjoining the hall is located the clerk's office, steward's room, baggage-room, and entrance to dining-room below. Abaft the social hall is a large room without berths, but provided with chairs and tables for the use of passengers without state-room tickets.

All of the main-deck space forward of the social hall is used for the stowing of freight, except such room as is re-

quired for wash-room for engineers, firemen, deck-hands, and crew, and room for steering-engine and steam capstan-windlass. A steam capstan is provided aft. The routes of these steamers cause the run to be made at night, so that the dining arrangement is a secondary matter, but ample provisions are made for dining, provided it should be necessary at any time, such as the steamer being delayed by fog or when on excursions, and the room provided is on the lower orlop deck abaft the engines. The dining-room, with galley and pantry attached, has a seating capacity for 120 people. The galley and pantry are on the forward side, and the cooks', waiters', and store rooms on the after side of the dining-room. The electric-light plant is forward of the boiler on the orlop deck and consists of two plants of 350 and 250 lights capacity. Forward of the dynamo-room on the same deck are the rooms for chief engineer, first engineer, and second and third engineers, porters' room, and lamp-room. Forward of this, well up in the fore-peak, room is had for berthing the rest of the crew, firemen, deck-hands, etc.

It will be seen from the side elevation that the engines are placed well aft and the boiler forward of the engines. The engines are of the compound, jet-condensing, beam type, with a high-pressure cylinder 44 in. in diameter by 8 ft. 0 in. stroke, and a low-pressure cylinder 68 in. in diameter by 12 ft. 0 in. stroke. Poppet-valves are fitted to both cylinders, with separate valves for the admission and exhaust, operated by eccentric, rock-shaft and lifters, and a Sickles drop cut-off. These engines turn feathering paddle-wheels 26 ft. 0 in. in diameter by 10 ft. 0 in. face with twelve buckets 40 in. deep. Steam is supplied to these engines from four single-ended Scotch boilers 12 ft. 0 in. in diameter by 11 ft. 0 in. long, each containing three furnaces 40 in. in diameter built to a working pressure of 104 lbs. of steam. The coal-bunkers occupy the central portion of the vessel between the boilers and have a capacity of 110 tons of coal, the coaling being done from the main-deck through scuttles.

This type of steamer requires a crew of 65 men, and, the engines indicating 2400 H.P., the vessel's speed light is 18.72 statute miles per hour.

We have now completed the description of the four principal classes of vessels engaged in traffic on the Great Lakes,

as referred to in the beginning of this paper; but, as was then intimated, four principal classes do not include all the "craft" that sail these inland seas. There are numerous other vessels engaged in the Lake traffic, a full description of which, if time permitted, accompanied by drawings illustrating the peculiarities of each, would no doubt be very interesting. A description of two of the more important ones (the whale-backs and the double-screw car-ferry), together with plans and sectional drawings showing their peculiarities, would be considered within the limits of this paper.

THE WHALE-BACKS.

The description of these vessels will necessarily be brief, in view of the fact that the inventor of this type of vessel is expected to give a full and complete description of them before this Congress.

Figures 45, 46, and 47 show midship and longitudinal section and plan, respectively, of a whale-back steamer 265 ft. over all, 38 ft. beam, and 24 ft. depth. From the midship section it will be seen that this vessel is built with a main-plate keelson 42 in. deep and side keelson on top of floors, spaced about 3 ft. 6 in., and decked over with plates, thus forming water-ballast tanks in the usual way, with the exception that the margin plate turns down at the bilge and connects to the outside plating at right angles, and the tank-top is not stiffened by athwartship angles, the number of longitudinal side keelsons being deemed sufficient. The wood covering is laid directly on the tank-top. The sides, midway between the tank-top and orlop beams, are stiffened by plate-stringers and belt-frames, and the hold is stanchioned off the entire length on each side of the hatches by angle-iron stanchions spaced about 8 ft. and connected to the orlop-beam as angles. The midship section shows the crown of the deck, which is semi-elliptical in form and is plated all over. The hatches are without coamings, except a small stiffening angle longitudinally.

The hatch-covers bolt down snug to the deck without the use of battens. Two rows of wrought stanchions are stepped into cast-iron sockets bolted to the deck outside the hatches, and extend the entire length of the vessel through which five

tiers of wire life-line are served. The hatches are about 11 ft. athwartships by 8 ft. longitudinally, and spaced 18 ft.

It will be seen from the longitudinal section that the machinery is located well aft as usual, and the funnel and engine hatches are trunked up to the spar- or cabin-deck by elliptical-shaped turrets upon which the cabin is built, and the cabin-deck is farther supported by hollow stanchions at the sides and front that are utilized for ventilators from the main hold. The boilers are located in the lower hold and, in this case, placed athwartships with the coal-bunkers on the forward side.

The drawing shows one single-ended Scotch boiler and a compound engine; the engine-room is supplied with ballast-pump and a system of piping for filling and discharging water-ballast.

The pilot-house is placed a little forward of the funnel and fitted with hand steering gear. The steam windlass is placed in the forward turret, which is decked over similar to those aft, and on this deck is placed the capstan and small timber heads for handling the lines. Below the deck and forward of the collision bulkhead are berthed part of the crew, and the rest are berthed on the cabin-deck. A steam capstan is placed in the after turret, with timber head and leading-chocks for handling the line.

Large timber heads or towing bollards are placed at each end of the vessel. These vessels are rigged with small poles for carrying lights and signals.

DOUBLE-SCREW CAR FERRY.

These vessels are designed to transfer cars across the Straits of Mackinaw in the winter through ice from three to five feet thick, and are built of oak and of very heavy construction.

The first one built is a vessel having a length of keel 201 ft., length over all 232 ft., beam 50 ft., and depth, moulded, 24 ft., as is shown in Figs. 48, 49 and 50, cross and longitudinal sections and deck plan. The vessel has two decks, as will be seen from the longitudinal section. The plan shows two lines of standard track, one on each side, sufficient to accommodate five cars each, and transport the same across the Straits

at a speed of 15 miles per hour. The cross-section may be taken as the midship section, and shows a great dead rise, with frames 24 in. deep at the keel, 20 in. at the lower turn of the bilge, 12 in. at the upper turn of the bilge, and 7 in. at the main deck, and of two thicknesses of 6 in. oak spaced 22 in. centres. In addition, the turn of the bilge is protected by short frames that extend from the keel to the water-line so that the lower portion of the hull is almost a continuous mass of framework. As will be seen, the keel-plank is 8 in. thick; garboards 7 in. in thickness, and the other planking up to the deck is 6 in. and ceiled on the inside from the under side of the shelf-piece to the upper turn of the bilge with 5-in. oak. The deck-beams are oak, 10 in. by 10 in., spaced 34 in. centres and connected to the sides of the vessel and to the top of a shelf-piece made up of two 6-in. and one 7-in. oak pieces, each 14 in. wide, and one piece 6 in. by 7 in., all kneed and drift-bolted through and through.

The main keelson on top of floor is composed of seven pieces of 14 in. by 14 in. oak, and side keelson one tier of two pieces 14 in. by 14 in., and two tiers of one piece each, 14 in. by 14 in., on each side; and on inside of the hull abreast of the water-line is placed a shelf-piece or stringer on which are stepped oak stanchions and a double row of I-beam stanchions amidships, to support the great weight on deck and to resist crushing in the ice.

The longitudinal section shows the manner of framing at the bow and stern. The track-rails are placed on top of heavy oak stringers 12 in. by 12 in., placed on top of the deck-beams, and the rest of the deck is laid with 4 in. by 4 in. pine.

The space between the tracks is utilized for cabins to accommodate the crew, and for waiting-rooms. These cabins are built up to deck, and on the forward side of the upper deck is located the pilot-house and texas or chart-room. The longitudinal section shows the construction in detail, all of which has been well designed for this particular service.

The vessel is propelled by two inverted, compound, jet-condensing engines, working on two separate shafts. The forward engine has cylinders 26 in. and 48 in. by 40 in., and the after one 28½ in. and 53 in. by 48 in., using steam at 120 lbs.

The forward propeller is 10 ft. 6 in. in diameter and the after one 12 ft. in diameter. The engines are supplied with

steam from three double-ended boilers of the "Scotch" type, 11 ft. 6 in. in diameter by 18 feet long, each containing four furnaces 44 in. in diameter, and the vessel has a capacity for 150 tons of coal in the bunkers. Hand windlass forward and steam steering gear in connection with hand gear is provided; the vessel is also equipped with electric light and a powerful search-light. The boilers and engines occupy the central portion of the vessel which will be on an even keel when loaded or light, and both engines can be used to propel the vessel in going ahead, or the forward engine can be backing and the after engine working ahead, which being more powerful will drive the vessel forward at a slower rate of speed, thus enabling her to work her way through very heavy ice. In order to protect the planking from damage by sharp hard ice the hull is sheathed from the keel to the water-line, the whole length, with ¼-in. steel.

A second vessel built on the same general plan has just been completed and will soon be put on the same route as the one described above. This vessel has a capacity to transfer eighteen cars and has an over-all length of 302 ft.; length of keel 269½ ft.; beam-moulded 50½ ft.; depth moulded 24½ ft. The vessel is built of oak, containing nearly 2,000,000 ft., and is sheathed with ¼-in. steel.

Two separate inverted, vertical, compound jet-condensing engines turning separate wheels are provided; the forward one has cylinders 28 in. and 52 in. by 40 in., and the after one 32 in. and 58 in. by 48 in. Steam at 120 lbs. is supplied by four double-ended "Scotch" boilers 11 ft. 6 in. in diameter by 18 ft. long, with four 44-in. furnaces in each.

The forward propeller is 10 ft. 6 in. in diameter and the after one 12 ft. in diameter.

XXXVII.

COMPARISON OF THE TYPES OF STEAMERS ON THE GREAT LAKES WITH REGARD TO STRENGTH, EFFICIENCY, AND LOCATION OF MACHINERY·

By JOSEPH R. OLDHAM, C.E., N.A., *Cleveland, Ohio.*

At the present time and in this country, changes occur with great rapidity. Tradition has no effect, and the novelty of to-day is old to-morrow. The greatest rewards are for those who project novelties which can be applied rapidly; so that it comes about that only he who can act quickly is considered a benefactor, albeit his actions may be wise in appearance rather than reality. The great object is always to save time and labor; and in the invention of such devices this country has always held the first place, not only for small things but even for such more important ones as ships.

With regard to models of ships, the writer has seen vessels whose transverse sections below the water-line were circular or convex, others with these sections concave, while others still had perfectly straight lines; and it is well known that the perfect cylinder and rectangular box form, in transverse section, have been, in their day, equipped and operated and called ships or even steamers.

We have also seen vessels with straight stems and others with curved ones; vessels with great sheer or little sheer: but here on the Lakes we have classes of vessels which differ from all these, in that some have no sheer while others have neither stems nor gunwales; yet such vessels have twice crossed the Atlantic and passed through the Straits of Magellan.

A splendid illustration of the rapid introduction of novelties of which I have spoken is the "whale-back" industry. Five years ago, when whale-back No. 101 appeared on these Northwestern Lakes, the greeting she received was ridicule, accompanied by prophecies of disaster and disgrace. To-day, these peculiar-looking vessels are generally preferred by American underwriters, while business with their designers and builders is eagerly sought. It may be that many of us do not appreciate the advantages of every detail of these vessels, but the fact remains that, on the Lakes, they are an unqualified success structurally and commercially, and they have taught us much that is new.

The fleet of the American Steel Barge Company now represents a capacity for marine transportation of not less than 100,000 tons. Under ordinary conditions, these vessels could transport from Two Harbors, Minnesota, to Cleveland, Ohio, a distance of 820 miles, about three million tons during the season even allowing that the return voyage is in ballast. This alone, however, does not give an adequate idea of the magnitude of the business brought about by the conception of the "whale-back." Vessels of this type are building on our Pacific coast and in England, and the industry has caused the building of two large shipyards with wharves and drydocks, of an immense steel works, and of a small city.

Since the advent of the "whale-backs" other types of vessels have appeared, variously called "monitors," "turrets," "straightbacks," etc., one of the largest of which, the "Yuma," was built under the superintendence of the writer, her dimensions being $324' \times 42' \times 23\frac{1}{2}'$.

There are two innovations peculiar to these vessels as constructed on the Lakes—an abrupt and somewhat large "tumble-home" (though not much greater than is frequently seen on the ocean) and an absence of sheer.

The following table gives some data of four of these "straight-back" steamers built under the writer's supervision, the first three being $275' \times 40' \times 26'$, for the Anchor Line of steamers. These vessels cost less than sixty dollars per ton of dead weight, as given in the table, and it may be mentioned that steamers for the ore trade are built to-day on the Lakes for fifty dollars per ton.

GENERAL PARTICULARS OF FOUR STEEL STRAIGHT-BACK STEAMERS.

	Displacement.	Dead-weight.	Load Draught.	Light Draught.	Equipped Weight.	Tonnage Efficiency.	Engines.	Boilers.		Screw.		
							Diameters and Stroke.	Dia.	Lgth.	Dia.	Pitch.	Area sq. ft.
	tons	tons			tons							
Codorus...	4340	3010	16′ 0″	5′8″	1320	1.67	$\frac{20+32+54}{44}$	14′ 0″	12′ 0″	12′ 6″	15′ 0″	58
Mahoning..	4230	2990	16 0	5 6½	1260	1.71	$\frac{20+32+54}{42}$	14 0	12 0	12 6	15 0	48
Schuylkill .	4400	3040	16 0	5 8	1360	1.67	$\frac{20+32+52}{42}$	14 0	12 6	13 0	15 9	52
Yuma*.....		3032	14 4½			1.96	$\frac{20+33+54}{40}$	13 3	12 6	12 6		

* Will carry 3620 tons at 16′ 0″ mean draught.

The average speed of the above Anchor Line steamers loaded is 13 miles per hour. A cargo consisting of 2500 tons of flour is frequently unloaded and 200 tons of fuel placed in the bunkers, both within twelve hours.

The "tumble-home" of these vessels is an improvement of form as compared with the common broad and light-draught Lake cargo steamer; for, in the latter, the angle or corner formed by the junction of the topsides and deck cannot easily be properly filled with cargo, so that it would seem that the "whale-back" form of topsides is the ideal one for broad ore-carriers, the "monitor" being an approximation to that form. These vessels have an advantage also in the measurement for register tonnage. As an example, a steamer of ordinary form, with the same dimensions as the "Yuma," will have a register tonnage about 15% greater, and a dead-weight capacity about 8% less, than the "Yuma." The difference in the register tonnage is due to the two upper transverse ordinates being less in the "Yuma" than in the ordinary vessel, while the increased dead-weight capacity is due partly to lighter hull and machinery, but principally to the change in form.

It is to be noted, however, that there are some apparent

defects, or at least some points of construction req
cial provision to meet peculiar stresses, in these sp
of Lake steamers.

The ordinary Lake steamer has a gunwale-angl
six inches above the deck stringer, as shown in
sheer-strake extending up to the same height and be
riveted to this angle. This, of course, adds to t
of the topsides in virtue of increased height of
leads to emphasizing the point that the omission
tical flange and extra height of sheer-strake in the
backs," as shown in Figs. 2, 3, and 4, compels t
plates to receive the initial stresses of compression

This is not merely a theoretical deduction, se
having come under the writer's observation wh
strakes and gunwale-angle-bars, connected in th
manner, have been fractured at a point about o
the length of the vessel from aft. He has also
stringer-plates cracked out from the corners of
hatchways in such vessels. But in the straight-b
flush deck transversely) the stringer-plates and
angles are the only parts showing distress, the s
and other parts not only remaining intact, bu
no signs of strain. It may be, of course, that th
tions are sometimes due to lack of material, as
deck stringer-plates and gunwale-angles are invaria
than the sheer-strakes. Such an arrangement see
writer, a mistake in vessels of this style.

A source of weakness in the ordinary Lake s
the number of immense openings for hatchways, wh
over, are not always in the centre athwartships; thi
is generally the cause of weakness in the upper wo
they are weak). The hatches range from 60 to 80
the extreme breadth of the vessel. In shallow
length (athwartships) of the hatches may be reduc
the "Yuma's" hatches are only 26 feet in a 42-
while in ordinary steamers of even 40 feet beam t
are 30 feet. The cargo hatches, moreover, are no
large openings in the decks. as the position of the
the main deck or a few feet only below it, frequentl
a reduction in the width of the stringer-plates to
their accommodation. However, this source of

is being overcome, as indeed it should be, for the large wooden Lake steamers are above suspicion, and their hatches are as large as those of the steel vessels, but it may be remarked that their builders are the most experienced in the world.

With regard to the second peculiarity of the "straight-backs," the absence of sheer, it may be said that this greatly facilitates the discharging and, to some degree, the loading of ore and other cargoes, as the deck of the vessel remains more nearly parallel to the water than would be the case if there were sheer forward. When there is the usual sheer, the forward tanks frequently have to be filled during the discharge of cargo, so that the work may go on continuously without having to raise the ends of the Brown hoists (each of which can lift 30 tons per hour a height of 30 feet and transport it 350 feet from the vessel). As there is a gain of efficiency from this type, it would seem that the appearance, at least to naval architects and engineers, cannot long remain distasteful, so that it would appear that, in deep Lake steamers, sheer can be omitted with advantage. In fact, there are now in service no fewer than forty steel straight-backs, aggregating nearly 100,000 tons, more than a fourth of the total tonnage of iron, steel, and composite ships. It may be added that many of them have an actual drop at the ends equal to their round of beam.

It would be interesting to learn if there is anything in the form of the topsides of these special types which affects their strength. As far as the writer knows, those of elliptical form without a gunwale-angle have not shown even severe signs of weakness on the topsides. These vessels are as long as others, and generally shallower; and the earlier ones were certainly not heavier than the ordinary Lake steamer in the ore trade, nor was the workmanship superior. It is true the hatchways are smaller, but then there are large gangways which must certainly weaken the topsides. On the whole, it appears to the writer that the continuous curve, extending into the form of an elliptical arch, adds greatly to the strength, at least transversely.

If we consider the stresses when the vessels roll, we shall see that, in the "monitor" type and in the ordinary type, to a smaller extent perhaps, the changes of stress from the sheer-strake to the stringer-plate are frequently abrupt, and

the gunwale-angle must feel this severely. In fact, it is sometimes ruptured. On the other hand, vessels without any gunwale-angle appear to stand the stresses best of all, and this is not merely opinion, but the result of observation.

Nothing has been said about the bottoms, as, in general, they are undoubtedly of ample strength.

It may be added, also, that many of the whale-backs are no heavier than other steamers, in proportion to their dimensions, although Mr. Saml. Mather's "Pathfinder" and her sister ships may be.

The great obstacle to continuous longitudinal strength in a cargo steamer with minimum scantlings is the weight and space required for the proper working of the boilers and engine, which necessarily includes the coal-bunker space. It has, therefore, occurred to the writer that a comparison of weight and buoyancy for the various parts of the vessel, and under the varied conditions of loading and steaming common to all cargo steamers, would be interesting, and with that end there are annexed the diagrams, tables, and curves shown in Figs. 5, 6, and 7.

It may be remarked, in passing, that in sailing-vessels the cargo may be so distributed that gravity and buoyancy practically balance each other; in other words, they are water-borne from stem to stern. When light, however, the still-water hogging moments coming on wooden sailing-vessels are frequently more severe than those in steel steamers when light. Hence, when laying up oak steamers and schooners for the winter, it is prudent to leave some cargo or ballast on board.

The principal cause of straining of the hull is the lack of balance between the hull weights and the buoyancy at all points, especially when steaming at certain speeds in shallow water, as the space occupied by the propelling power prevents the load being evenly distributed.

Figs. 5, 6, and 7 show the distribution of weight and buoyancy in three different positions in steamers of the same size and power.

The arrangement with the machinery about amidships (Fig. 5) is the most inconvenient for loading and discharging, and it also causes serious variation between load and buoy-

ancy, but it is the best possible position with regard to trim or change in draught during a voyage.

It may be well to state, in this connection, that most of our ore-loading chutes and the Brown hoists also are arranged for hatchways 24 feet apart from centre to centre, and although the spacing of the latter may be varied, some time and trouble is required for the operations. As many of our liners are required to arrive and depart with greater punctuality and often with greater mean speed than the average long-distance freight-train, the importance of even a little lost time in port is appreciated.

The medium position (Fig. 7) is the best possible, with regard to variation of load and buoyancy, with an ordinary cargo, but it is inferior to the amidships position as regards trim, in that it causes greater variation of draught from the filling and emptying of the coal-bunkers. It is inferior to the aftermost position with regard to facility of handling cargo.

The aftermost position (Fig. 6) is the best possible for facility of loading and unloading, but is inferior to the amidships position when the hull stresses in light condition or ballast are considered. As soon as the cargo is put on board, however, this inferiority disappears, for, when the hull is fully loaded, the aftermost position for the machinery is about the best as far as uniformity of stress on the hull is concerned.

It would appear, therefore, that the aftermost position for the machinery is the best, even though it may cause a change of draught of six inches, due to the varying amount of coal in the bunkers (which corresponds to about 250 tons of dead weight in one of our largest steamers), and it is the most popular.

Although it would seem that this choice of position of machinery should be a mechanical problem, it is really decided by commercial considerations, which have fixed upon the aftermost position. This is probably correct for coasting or short voyages, and it is easy to keep within limits any excessive vibration and danger of straining when light in shallow water.

We should remember, however, that when the engines are amidships there are necessarily two and sometimes three athwartship bulkheads there, and these are the best means

of preventing change of form transversely resulting from racking stresses. It is not an easy matter to construct a large steamer of sufficient strength transversely, with an ordinary quantity of material, without having a second steel deck, or hold beams and stringers, to distribute the rigidity between the bulkheads so that there may be sufficient horizontal longitudinal strength.

A few years ago, when the writer was superintendent of a line of general cargo steamers and screw colliers, in which there were vessels having their engines amidships and others having them aft, the owners were so convinced that the after location was the best for their trade that they went to great expense in one steamer in moving the machinery from amidships to aft. The results in actual work justified the change.

In the writer's opinion, the most serious stresses are not the longitudinal hogging stresses, but rather those due to sagging and torsion, which alternately expand and compress the topsides and decks, such as would be developed when the vessel's centre of gravity has passed the momentary centre of buoyancy, as on the crest of a wave. The bow would then fall into a rising wave, while a large portion of the vessel amidships is wholly unsupported. These stresses tend to cause the decks amidships to rise and flatten, and also the topsides to pant. Hence arises the necessity for good transverse strength, which is fulfilled by large web-frames, firmly kneed or bracketed to the upper bottom and decks, as well as good longitudinal hold stringers to distribute the horizontal stresses among the web-frames and bulkheads.

Some very light steamers were built on the Lakes within a few years, and there was danger of more being constructed, but happily it has passed, for the present at least. Recourse has been had to a good deal of plate doubling, evidently for the increase of longitudinal strength, and it may have been needed for the topsides, but more strength is being added to the bottom than to the top. One vessel has had six keelsons and stringers added below the main deck, and other analogous additions have been made elsewhere, much to the credit of our ship-builders and owners.

It should not be forgotten that, although some of our tank tops are somewhat thin for the duties often imposed on them,

they are continuous. The bottom is, of course, which latter alone is the factor that causes the longitudinal neutral plane of Lake steamers to be as low down as 65% of the moulded depth below the gunwales, as may be seen by the calculation of moment of inertia for a screw-steamer 285′ × 40′ × 26′.

Distance of neutral plane below gunwale . . .	17.2 ft.
Moment of inertia	46,041.12
Displacement at 17 ft. mean draught	4,720 tons.
Length on upper deck	285 ft.

Coef. of longitudinal strength $\dfrac{4720 \times 285 \times 17.2}{46041.12} = 50.29.$

Approximate bending-moment at the gunwale:

Ashore	50.29 tons per square inch.
Afloat	10.06 " " " "

It may console the owners as well as builders of *good* thin steamers, that the thin steamers are not the only ones which have shown signs of distress. Some of the very heavy vessels have suffered even more than the *good* thin ones.

It would seem that it is not so much an increase in shell-plating that is required, as greater strength in the framing, beams and stringers; and it is hardly necessary to say that the function of these—at any rate, the first—is to afford transverse strength. In many instances, the lower part of sheer-strake and topside plating are found severely strained, while the upper stringer-plates are not distressed. What can cause this except lack of transverse strength? Those vessels with the heaviest beams and frames have best stood the test of actual work.

Finally, a few words may be said relative to the materials of which the steamers are built, and their scantlings.

In the early days of steel-ship building, some bad steel was certainly put on the market. Some was so bad that, after incorporation into the hull, it had to be cut out. One experienced ship-builder has so little faith in the reliability of steel after it has been locally heated and flanged—and he appreciates the benefits of annealing—that he makes all his flanged

keel-plates and boss-plates of *iron*. In the writer's opinion this practice is commendable, for it is not an uncommon thing to see several plates used up in making the after-keel or boss-plates of a steamer. Still, it is probably true that defects are charged to the steel which do not properly belong to it.

Even if we had the best steel that could be produced, this alone would not insure a strong, staunch, and good ship, for in some cases there is too little of it worked into the structure. If the ship-builder were always careful to make his ship heavy enough, he would then have a good excuse for abusing the steel if things went wrong.

Although the manufacture of mild steel for ship-building is a comparatively new industry in this country, recent correspondence with most of our great firms shows that at least six of them make large quantities of both Bessemer and open-hearth steel for ship-building. As an example of the rapidity with which steel can be supplied, it may be said that the steel-makers can meet the demands of the most rapid repair work, and our yards can repair steel vessels as quickly as any. Steel plates ordered one day are usually furnished the next.

The writer would venture the prediction that the "whale-back," or some new modification of that type, will be the type of ore and pig-iron carrier of the future, while a true spar-deck steamer of ordinary form, with a straight main deck, if sufficient depth can be retained, will be the general cargo carrier for the Lakes. We now have several steamers, which have done good service, with their upper sides and decks weaker than is common in spar-deck steamers; but the great height of the latter is a positive objection to their use for the *ore trade*, to say nothing of their increased register tonnage, first cost, and insurance. No vessel can be an ideal dead-weight carrier and light-goods transport as well. A good iron-ore carrier cannot be an efficient general-cargo or package-freight steamer, any more than a hay-rack would be suitable for carrying pig-iron.

The following table, kindly supplied by Col. Jas. Pickands, gives particulars of the performance of one of a fleet of steamers under his management, whose record as ore-carriers cannot be excelled:

OPERATIONS OF STEAMER "MANOLA," 292' × 40' × 24½'.

(One of the Minnesota Fleet of Cleveland, Ohio.)

Per cent of operations to earnings	58.79
Earnings per ton per mile	.00078
Operating expense per ton per mile	.00046
Net earnings per ton per mile	.00032
Earnings per mile travelled	1.853
Operating expense per mile travelled	1.090
Net earnings per mile travelled	.763
Total miles travelled	50,584
Average miles travelled per day	227½
Tons freight carried	71,170.69
Tons freight carried one mile	3,600,078,861
Average speed per hour light	12.72
Average speed per hour loaded	11.85
General average speed per hour	12.25
Total tons fuel used	5523
Average tons fuel used per trip	184.553
Average amount fuel per mile light........lbs	209
Average amount fuel per mile loaded..... "	226
General average amount fuel per mile..... "	218
Average fuel per ton per mile............oz	1¼
Number of trips	30
Average size cargo....tons	2295.82
Average draught water Sault Canal, feet	14' 7"—14' 9"
Average time loading............hrs	7¼
Average time unloading.......... "	12
Average time handling cargo...... "	19¼
Average tons loaded per hour	306.244
Average tons unloaded per hour	191.712
Average tons handled per hour	235.105
Actual time sailing..........days	175
Actual time in port.......... "	47
Actual time in commission... "	222
Per cent of time sailing	.7883
Per cent of time in port	.2117
Average number crew each trip	23
Average wages crew each trip	334.05
Average length of trip....days	7.396
Average mileage per trip	1686

Coal, short tons; cargo, long tons.

DISCUSSION ON COMPARISON OF THE TYPES OF STEAMERS ON THE GREAT LAKES WITH REGARD TO STRENGTH, EFFICIENCY, AND LOCATION OF MACHINERY.

MR. JOHN C. KAFER:—I would like to ask Mr. Oldham what he claims for the vessels constructed on the Lakes over those constructed on the Atlantic seaboard. Superiority has been claimed for the whaleback steamer as a carrier, but I am sure there are freight steamers running out of New York that carry their freight quite as economically per ton-mile as any of the whalebacks, besides being stronger and better fitted for the trade.

MR. OLDHAM:—In reply to Mr. Kafer I may say that the comparison in my paper was not between lake steamers and ocean steamers, but between lake steamers and lake steamers; and I do not know that I could make such a comparison as Mr. Kafer suggests that would interest you. I know that they build very excellent vessels on the coast, and we build very excellent vessels on the Lakes, and I think that the two together will bear favorable comparison with any ships in the world.

MR. GEO. W. DICKIE:—One of the objects I had in coming to Chicago at the present time was to look into the lake shipping, and I have not made the acquaintance yet of any number of the gentlemen engaged in this work here; but I just want to say that I am going to be here a little while, and I am going to Cleveland, and I want to see all that can be seen in lake shipping. I am very much interested in it, and it is a question of vast importance. The enormous amount of shipping that has been developed on these Great Lakes, the amount of freight, as I notice by this table, is something that to one coming from the seaboard to the centre of the country is a revelation, to find that this business has assumed such enormous proportions. I trust that those interested will not let me go away without being a little better posted than I am now on lake shipping.

MR. OLDHAM:—In endeavoring to be brief, I hope I have not

been discourteous in replying to Mr. Kafer. I can only say this, that all I know at the present moment is in this paper, and therefore it would be useless waste of your time for me to repeat it; but if there is anything specific that Mr. Kafer wishes to know, or any of the gentlemen, I will be pleased to answer.

CHAIRMAN LORING:—I think Mr. Kafer wished you to give a comparison between the lake steamers and the ocean steamers.

MR. OLDHAM:—On the seaboard I think you are very largely governed by the registration societies. Such has not been the case on these Lakes. The registration societies are doing but little in that way; but really many of our vessels are built in advance of all the rules as they are published by our registration societies, and I am not sure that they are any the worse for that. I think it is rather a good thing to give the ship-builder a free hand,—to be supervised in some degree, to be sure, to see that there is sufficient material there; but at any rate I am certain this is true, that the freer the ship-builder is, the greater variety we will have, and the sooner will we get at the best type of ship.

MR. E. PLATT STRATTON:—As representing one of the registration societies of this country, I would ask if the steamships "Gilcher" and "Western Reserve" were built under the rules of any registration society.

MR. OLDHAM:—In reply I may say that so far as I know they were not built under the rules of any registration society; but never having been on board of the "Gilcher," and only once for an hour or two on board of the "Western Reserve," and that some two or three years before she was lost, I cannot speak with authority.

MR. OLDHAM (reply in writing after the meeting):—In reply to my friends, Mr. Dickie and Mr. Kafer, I may say,—and that at the risk of repeating a portion of my paper,—that our modern lake tonnage is composed of two great classes, viz., dead-weight carriers, principally engaged in the iron-ore trade; and general cargo steamers, chiefly owned or controlled by the great railroad companies; and the carrying capacity of the latter class amounts to about one hundred thousand tons.

As regards the models of these steamers, they are not very dissimilar to ordinary ocean steamers, except that they are somewhat shallower in proportion to their breadth, the average depth being about 65 per cent of the mean breadth, in comparison with 70 per cent as the ratio obtaining in ocean steamers. Then the rise of floor in our steamers is about a quarter of an inch per foot half-breadth of beam, this being about one third of the average deadrise in ocean steamers.

The displacement coefficient of lake steamers is about .81 against .78 in coast steamers. Our steamers are generally fitted with balanced rudders; and when these are properly proportioned no power is required to turn the rudder beyond that necessary to move the water, and to overcome the *vis inertia* and friction of the one pintle and the bearing on deck or at the counter. Should it be thought that these rudders may be weak laterally, I may state that the White Star royal mail steamer "Britannic" had no keel-piece abaft of her propeller-post; consequently her rudder was altogether unsupported at the heel, and it gave no trouble, for that steamer was classed by the "Veritas" after my survey.

I consider the balanced rudder a great improvement on the ordinary ocean type; indeed, that has apparently been proved, for we have two very large steamers here which have recently had their rudders changed from the ordinary coast type to the usual lake balanced type, and the owners claim a great improvement as resulting from the change. These rudders may get knocked largely out of line without disablement, whereas with two or three pintles connected to the stern-post the rudder cannot be turned when so injured. Our stern-bearings are adjustable with the ship afloat; this is a necessity here, for lake steamers frequently run for two or three years without going into dry-dock.

The lake steamers have from eight to ten cargo hatchways spaced 24 feet apart centre to centre, the length of these hatchways being about 70 per cent of the breadth of the vessel, by 8 feet wide in a fore-and-aft direction. Such hatchways might be found advantageous in coasting steamers engaged in the ore, coal, or grain trades, when they are regularly employed in these trades.

Our boilers being raised almost up to the main deck is a necessity with the engines right aft, as the vessel would be "by the head" when loaded with grain or coal if there were no space under the boilers for cargo.

Of course, with the same height of stack above deck, the boilers being raised above the level of the sea ought to be harder to fire; but we think this is not so, and it may be accounted for by the large boiler-house and good ventilation. But however that may be, the engineers and firemen have a strong predilection for the raised stokehold, which is also adopted here, even when the boilers are located about midships.

Another advantage of the raised stokehold is that the boilers can be emptied overboard without blowing down.

I think the cabins on lake steamers are peculiarly large and handsome for cargo boats; but it may be that these will soon be

greatly reduced, as some of our ship-owners appear to be disinclined to continue providing accommodation and provision for some ten or twelve guests during the lake season of navigation. A strange feature of the accommodation is that all the sleeping-berths are placed athwartships.

As regards the typical ore-carrier, the tendency is to make her shallower—to reduce the freeboard in fact; and we now have steel steamers of about sixteen times their depth in length. Of course in such steamers there should certainly be no reduction of scantlings at their upper deck; this, however, has been carefully provided for in the Great Lakes Register of Shipping Rules.

There is another class of lake vessels which are quite a contrast to the above, for they are simple in the extreme, and having abnormal tumble-home they probably roll easier than the ordinary steamers, which have their extreme breadth almost as high as the upper deck. Such vessels when heeled to an angle of 36° have a righting-moment of 8000 foot-tons. A steamer of similar displacement and proportions but with elliptical topsides has only 6250 foot-tons righting-moment at the same degree of inclination, but even less than this would be desirable with a sufficient range of stability.

The Minnesota fleet and many other steamers regularly steam a distance of over 1600 miles and load and discharge 3000 tons of cargo all within the week, including stoppages at the Sault Ste. Marie Canal, and "slowing down" over Lake St. Clair and other shallow waters.

The officers and crew keep "watch and watch," or six hours on deck and six below.

But little ingenuity has been displayed in the arrangement of the weather-decks on these lakes. Such extraordinary conceptions as raised fore-decks, long quarter-decks, and other "well" deck arrangements, are almost unknown to lake practice; our steamers are simple flush-deck vessels.

I am aware that with some artistic designing and artful loading an advantage may be achieved over the tonnage laws and the load-line act by raising the decks by steps of 3½ to 4 feet each over the after and midships body of the vessel; and then by loading sufficiently "by the heel" the steamer may have a respectable nominal freeboard at the lowest exposed part of her main (weather) deck, while the load-line disk at mid length is actually submerged. Some eight years ago I illustrated this at an important wreck inquiry into the loss of the S.S. "Bendigo," and I think the drawing proved somewhat interesting, if not startling. (See cut opposite).

So, notwithstanding some little difficulty in making a flush-deck

steamer a handy vessel to trim "by the heel" (the necessity for which is by no means universally admitted), on account of the cargo space shut out by the tunnel, I am still of opinion that our lake ship-owners and ship-builders have shown the best judgment in tenaciously adhering to the flush-deck vessel. I repeat this, notwithstanding the splendid advocacy or rather special pleading, by pen and pencil, so frequently advanced in favor of "well-deckers" for all but very small craft, in which a departure may be necessary to gain more floor-space, head-room, air, and light in rough weather, and secure more buoyancy at the ends when the freeboard is small.

The idea of cutting a large ship's decks near midships for the purpose of raising one portion of the decks above another exposed portion is like fitting a steam-dome to a boiler not deficient in steam-space. Both adjuncts would be better incorporated in the main body, as there the additional capacity could be added with general economy, and the increased space would be a definite gain and not an imaginary advantage, and that frequently acquired at the expense of strength and safety.

DOUBLE WELL DECK STEAMER

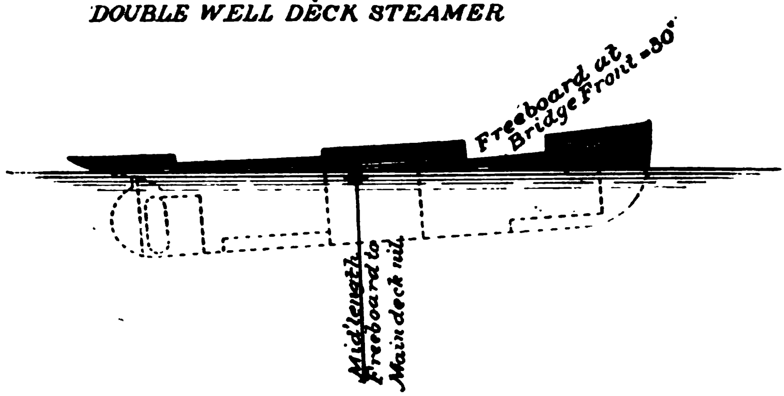


Fig. 1.

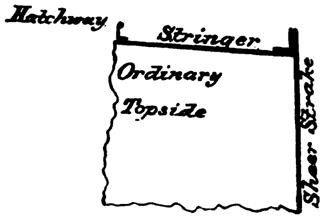


Fig. 2.

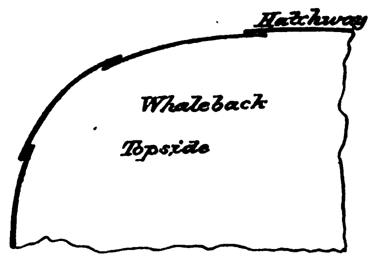


Fig. 3.

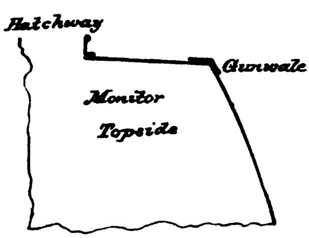


Fig. 4.

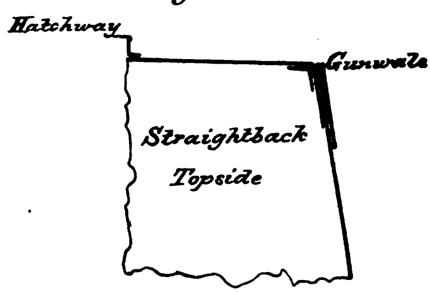
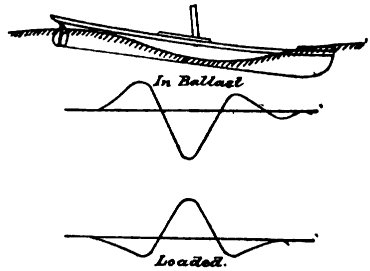
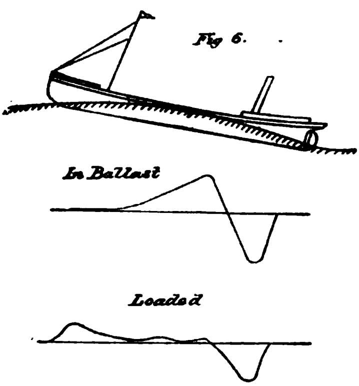


Fig. 5.



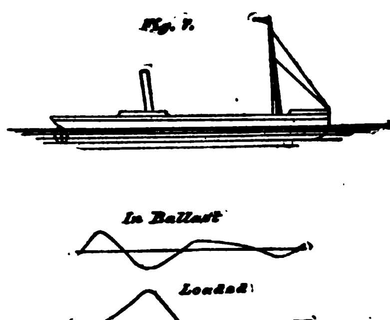
Ballast.				Loaded			
Weight	Buoyancy	Weight Excess	Buoyancy Excess	Weight	Buoyancy	Weight Excess	Buoyancy Excess
255	257		2	660	665		5
260	428		168	1200	1026	174	
1015	590	425		735	1085		350
480	730		250	1200	1026	176	
465	470		5	665	660	5	
2475	2475	425	425	4460	4460	355	355

Fig 6.



Ballast				Loaded			
Weight	Buoyancy	Weight Excess	Buoyancy Excess	Weight	Buoyancy	Weight Excess	Buoyancy Excess
257	250	7		402	660		258
400	428		28	1000	1026		26
460	590		130	1050	1085		35
410	730		320	1000	1026		26
948	477	471		1008	665	343	
2475	2.475	478	478	4460	4460	343	343

Fig. 7.



Engines in Medium Situation.

Ballast				Loaded			
Weight	Buoyancy	Weight Excess	Buoyancy Excess	Weight	Buoyancy	Weight Excess	Buoyancy Excess
355	257	98		660	660		
365	428		63	1200	1026	174	
540	590		50	1200	1085	115	
895	730	165		735	1024		289
300	470		170	665	665		
2475	2475	263	263	4460	4460	289	289

XXXVIII.

THE CONSTRUCTION OF STEAMBOATS NAVIGATING THE WESTERN WATERS OF THE UNITED STATES.

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Wheeling, West Va., U. S. A.

It is perhaps unfortunate that it cannot be definitely settled when was the date of the first attempt of navigation of boats propelled by steam.

In a work, published some forty years since in Spain, of original papers relating to the voyage of Columbus, preserved in the royal archives at Samancas, and those of the Secretary of War of Spain, in 1543, it is stated "that Belasco de Garay, a sea-captain, exhibited to Charles V., in the year 1543, an engine by which the largest vessels could be propelled even in a calm sea without oars or sails. The emperor decided that an experiment should be made, which was successfully attempted June 17, 1543, in the harbor of Barcelona. The experiment was on a ship of 209 tons, called the "Trinity." Garay never publicly exposed the construction of his engine, but it was observed at the time of the experiment that it consisted of a large caldron of boiling water, and a movable wheel attached to each side of the ship.

From this statement, it would appear that De Garay not only originated the steam-engine, but made at the same time its application in one of its most practical and beneficial forms, and at a single effort accomplished that which took the light and talent of several generations to invent and bring to practical shape.

This statement, although based on the archives of Spain, and those of the Secretary of War of that kingdom, are by some discredited, as the date is fifty-four years before the birth of the Marquis of Worcester, who is given by history the credit of being the inventor of the steam-engine. It might

be said in rebuttal, that the incident just quoted, of "De Garay's" experiment, possibly came in some way to the Marquis' notice, and that he proceeded, after the manner of all inventors, to improve upon it. There is also a fact in history as to an early steamboat that might justify the belief that both Fitch and Fulton were not entirely original in their idea of a boat propelled by machinery moved by steam, presuming even that De Garay's exhibition in 1543 had not accidentally come to their knowledge.

A treatise was printed in London in 1737 describing a machine invented by Jonathan Hulls, for carrying vessels against wind and tide, for which George II. granted a patent for fourteen years. A drawing is attached to the treatise, showing a boat with a chimney smoking, and a pair of wheels rigged over each side of the stern. From the stern of the boat, a tow-line passes to the foremast of a two-decker, which the boat thus tows. This is evidently the first idea of a steam tow-boat. As this was a published treatise and there was a patent on record, public information of a steamboat must have circulated before the experiments of Fitch and Fulton, or Stevens or Livingston; and while similarity of ideas in inventions are not infrequent, absolute originality is difficult to establish.

It would seem from the following extract from a diary kept by James Kenny, a Quaker trader at Fort Pitt, in 1761, that the Western waters of the United States had originated some of the first germs of the ideas of steamboat propulsion. The extract is:

"1761, 4th mo., 4th: A young man called Wm. Ramsey has made two little boats, being square at the sterns and joined together at the sterns by a swivel, make the two in form of one boat, but will turn around shorter than a boat of the same length, or raise with more safety in falls and in case of striking rocks; he has also made an engine with wheels that goes in a box, to be worked by one man, by sitting on the end of the box, and tredding on treddles at bottom with his feet, set the wheels agoing which work scullers or short paddles fixed over the gunnels turning them around, the under ones always laying hold in the water will make the boat go as if two men rowed, and he can steer at the same time by lines like plow lines."

This was twenty-five years before James Ramsey, of Berkeley County, Virginia, succeeded in propelling his flying boat, as it was called by the people, against the current of the Potomac at Shepherdstown, by steam alone, at the rate of four or five miles an hour, and also twenty years before Fitch in 1780, accidentally meeting Ramsey in Winchester, imparted to him his idea of propelling boats by steam.

After all, the preliminary experiments to which history, so far as recorded, give full credit, seem to be preliminary to the practical results obtained by Fitch and Roosevelt, who at Pittsburg in 1810 and 1811 constructed a boat called the "New Orleans." This boat was 138 feet length of keel; her cabin was in the hold, and she had port-holes, also a bowsprit eight feet in length (painted sky-blue), in ocean style; her cost was $40,000. She was launched in March and descended the river to Natchez in December, at which point she took in her first freight and passengers, and thence proceeded to New Orleans on the 24th of the same month. She continued to ply between New Orleans and Natchez until 1814, making the round trip in ten days, conveying passengers at the rate of $25 up and $18 down. On her first year's business she cleared $20,000 net. In the winter of 1814 she was snagged and lost at Baton Rouge.

Until 1814, there seems to have been no attempt to return boats from New Orleans to the head-waters of the Ohio River.

The "Enterprise" was built at Brownsville, Pa., and made two trips to Louisville; later in the year she proceeded to New Orleans, carrying a cargo of ordnance, and she was for a time actively employed in transporting troops.

In 1817, this boat left New Orleans for Pittsburg, and arrived at Louisville twenty-five days out from New Orleans, which event the citizens of Louisville celebrated by a dinner to the captain.

In 1816, the "Washington," built at Wheeling, was the first boat to have her boilers placed above the deck.

In 1818, the "Independent," fifty tons, was constructed for the Yellowstone expedition, and was the first steamboat that ascended the Missouri River.

In 1819, the "Western Engineer" was the first boat to ascend to Council Bluffs, 650 miles above St. Louis.

The successful operation of these boats had, by this time,

demonstrated what could be done, and from that time on, the construction of boats for the navigation of these waters has been continuous.

The navigation of such streams as the Ohio and Mississippi rivers is a problem entirely distinct. On these Western waters, only average results can be expected; boats must go, and make something near schedule time, whether the depth of the water in the channel is 30 inches or 30 feet, so that the first desideratum is minimum weight and maximum power, with all possible displacement of hull, per each unit of immersion, at all in keeping with anything like shape.

In boats designed for combined freight and passenger business, the hulls are constructed with all the lightness in any way consistent with safety against falling to pieces, and the machinery must have small diameter of cylinder and boilers, and consequently must be designed for high steam-pressure.

The character of the valve-gear employed in the engines is particularly adapted to the class of boat being considered, because better fitted to the requirements of the service, the boats being very raft-like and limber; overloading at any point will distort their shapes; "tight on their chains" when without load, "slack on their chains" when loaded. So, throughout the process of loading and unloading, one or the other effect constantly going on; these in turn perceptibly vary the distances between the centre of the main shaft and "rock shaft." Now, the lever valve-gear allows this variation without seriously affecting the timing of the valve movement; no other form of valve arrangement gives this very necessary quality of stretching.

Gradually, through the past years, side-wheel boats have diminished in number and tonnage, and stern-wheel boats have increased. At best, any of these wooden boats are perishable, and the vast difference in first cost and the cost of maintenance of the side-wheeler over the "wheelbarrow" boat has determined investments in favor of the latter; and while, to outside appearance, the stern-wheel boat of to-day is identical with that of twenty years ago, it is only so in that particular. The method of hull and joiner construction is much the same. Models have materially altered, and have carried with them, or perhaps been caused by, broad changes in the application

of the rudder or steering arrangements. This article, therefore, will be confined entirely to the stern-wheeler, as representing the most successful and recent practice.

For some time after the use of steam-propelled craft on the Western waters began, it was considered impracticable to bring the boats to a landing without first bringing them to anchor out in the stream; a line was then taken ashore in the yawl, and the boat hauled to the bank by the shore-line. When the boat left the landing, a reverse of this operation swung her to the anchor cable; the anchor was then lifted and the boat proceeded on her way.

The method of procedure has been very much improved. Now, in making a landing (and it must be understood that in this navigation boats land on the shore, and not against a dock of any kind, in the majority of cases), the boat is headed for the shore, the machinery stopped and reversed until the headway is nearly checked, the remaining headway being sufficient to carry the boat to contact with the shore, and so the landing is accomplished.

This practice is very much more expeditious than the old method, and has been brought about by the necessity of saving time in making landings, since the number of landings made by boats navigating these waters has vastly increased since their introduction.

The writer has in mind a so-called trade between two points about one hundred miles apart on the Ohio River. When the boats first entered the trade, some forty years ago, they made a maximum number of landings, in a round trip between the points, not exceeding thirty-five or forty. At the present time, boats in this same trade make never less than one hundred and fifty landings, usually exceeding two hundred.

The banks of the Ohio River are fast being filled with railroads which parallel the stream. This development has increased the volume of business done in the valleys, and has increased the amount of water traffic, although largely changing its character.

Prior to the railroad development, higher rates for service were charged by the boats than since, and the necessity existed for surplus boats of very light draught, which could be operated during the extreme low-water in the river. When

these boats were called into commission, rates for both freight and passage were usually increased. At the present time, the extreme low-water boats are fast disappearing, because their navigation is attended with a considerable increase of expense over what might be called normal conditions, and the competing railroads prevent any increase of tariff charges by the low-water boats over the regular normal charge.

One noteworthy labor-saving device, which is now almost general on Western boats, is a method employed for handling the stage-plank. Formerly, the stage-plank consisted of rough boards about 18 inches wide, 3 inches thick, and 24 feet in length. These planks were pushed out by the deck-hands, and in many instances—where by reason of flat shores the boats could not come in close to the water's edge—were rested upon a trestle set in the water, and a second section of plank reached from the trestle to the shore, a number of planks being placed side by side, making sufficient width to receive whatever freight there might be to handle.

This method of constructing a gangway was very slow and liable to be tripped or broken up by the waves of passing boats, or by the movement of the boat itself from which the gangway was constructed.

Of late years, a gang-plank has been adopted which is technically called a stage, varying in dimensions according to the size of the boat, but is usually about 8 feet wide and some 35 or 40 feet long. This stage is suspended in the middle, and is carried on a swinging crane which is attached near the forward end of the boat, and so arranged that the stage can be lifted through a tackle operated by a hoisting engine. Occasionally the stage is balanced by a weight, so that the use of the engine is dispensed with. On some of the boats, two of these stages are used—one on either side near the forward end of the boat; but, generally, one stage is used for both sides, the derrick of the crane being in the centre of the the forward end of the boat.

Both of these methods will be understood by reference to the cuts of the steamers "Fleetwood" and "Hudson" at the end of the article. Also at the end are cuts made from actual photographs of three boats: one called the "R. R. Hudson," built in 1865; the next, "Hudson," built in 1878; and the third, "Hudson," built in 1886. The boats are typical of the

improvements of recent years, so far as the outward appearance is concerned, and represent a marked increase in dimension of hull, the "R. R. Hudson" being 180 feet long, 32 feet beam; the "Hudson," 200 feet long, 34 feet beam; and the last "Hudson," 235 feet long and 36 feet beam.

A story is related by some old boatmen that, some time between 1820 and 1830, three men, who had been navigators of floating boats on the Ohio River, entered into a partnership for the purpose of having constructed a steamboat. The boat was to be 95 feet long. Shortly after the contracts were closed, one of the parties to the enterprise proposed to increase the length of the boat to 110 feet. A meeting of the parties was held to consider the proposition, and two of them agreed that the length of the boat should be 100 feet; the third, not willing to consent to this increase in the length, withdrew from the partnership, because he did not believe so large a boat could be successfully navigated through the crooked channels of the Ohio River.

These early ideas seem very faulty and are hard to understand, when we consider that, in the present day, the same channel of the Ohio River is navigated by boats 350 feet long, and by boats with tows rigidly attached to them, the length of boat and tow reaching as high as 900 feet; and would rather lead one to the reflection that perhaps we, with our ideas of progress to-day, are as wide of the mark as was the man who refused to invest in a steamboat 100 feet long, for the reasons given.

Fig. 1 indicates in plan the water lines of a recent light-built boat; Fig. 3 half bodies, and Fig. 2 side elevation showing sheer lines, etc.; Fig. 4 is a fore-and-aft section of a part to show method of fastening, proportion of timber, etc., in the hull; Fig. 5, a cross-section through one of the frames.

Fig. 6 is from a photograph of hull on the stocks. In connection with the figures, the following table of specifications indicates full dimensions:

Length, 180 feet.

Beam from out to out of frame, 33 feet.

Depth at lowest place in wing, 4½ feet.

Floors, 3½″ × 6″, centred on 14″ forward; to 2¾″ × 6″, centred on 16″ aft.

Main keelson, 5″ × 10″, made of four pieces 2½″ thick × 5″.

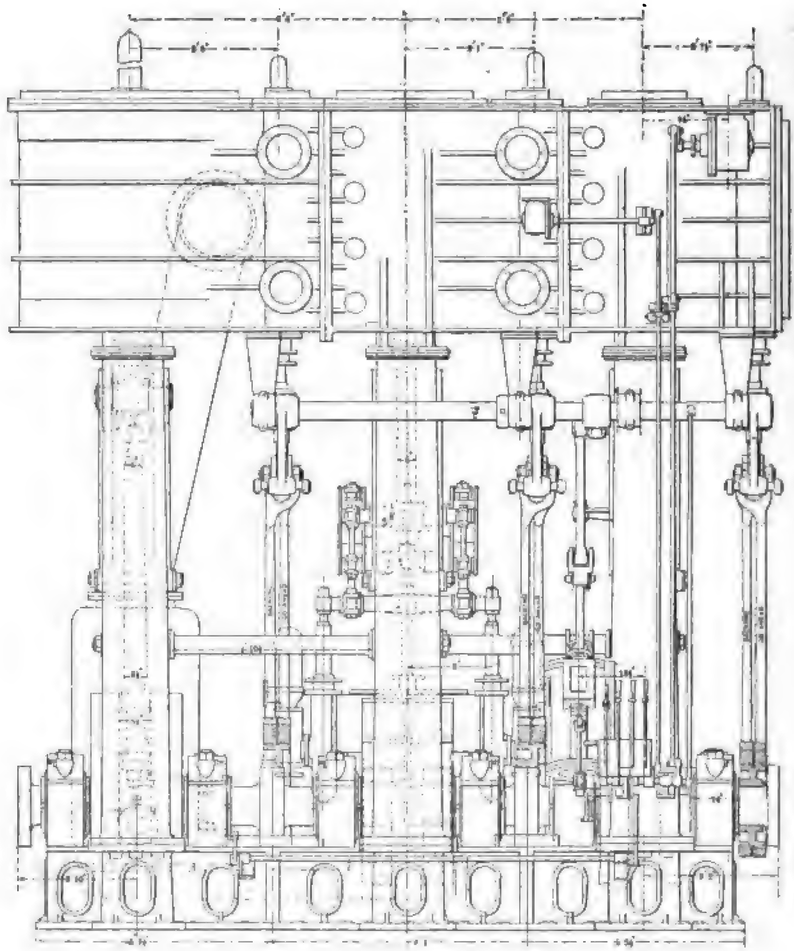


Fig 19.

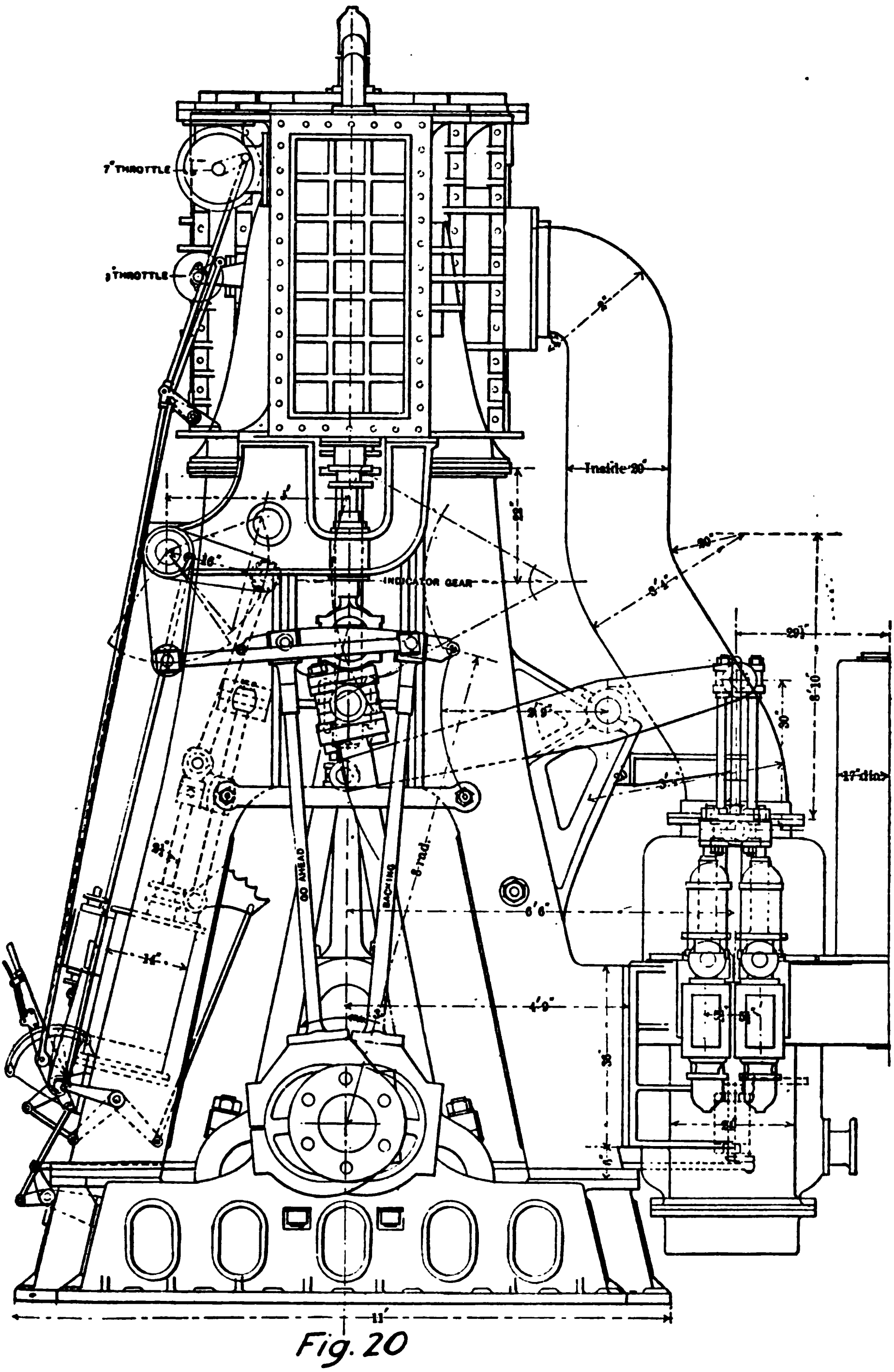

7" THROTTLE
3" THROTTLE
Inside 20"
INDICATOR GEAR
29½"
17"dia.
GO AHEAD
BACKING
8 rad.
6'6"
4'9"
11'

Fig. 20

in 1873, work radical changes in construction. These rules, about coincident with the introduction of steel boiler-plate, based the allowable working pressure of steam upon the tensile strength of the material. Now, a high steam-pressure is the great desire of every boatman's heart, and at once the greatest tensile strength obtainable was demanded. Seventy thousand pounds was generally adopted, but in some few cases 80,000 pounds was attempted. The amount of carbon, however, required in such plates at that period of steel-plate development produced some very unsatisfactory results, and the further action of the supervisors requiring a reduction in area of at least 50% for plate 0.26 inch thick has brought the commercial product down to about 65,000 tensile strength.

Many reflections are cast upon the plan of boiler and furnace in use on the boats under discussion; and no doubt to the outsider, who never stood over a steam-boiler with 200 to 225 pounds pressure on it all day, the forms used seem very crude and wasteful of fuel; but the fact remains that, while many radical changes have been proposed and attempted, the result has generally been a speedy return to the accepted form.

In the first place, a furnace construction which will generate 90 or 100 pounds of steam working-pressure with the greatest fuel economy will not generate 180 to 200 pounds with the greatest fuel economy; in fact, it usually will not generate the last pressure at all. Change of form is absolute, and ordinarily that form of furnace which makes the desired result with the least manipulation gives the best economy.

The plan of boiler most in use is the externally-fired return-flue type, shell 40 inches diameter, 24 feet long; two return flues 13 inches, sometimes 14 inches, diameter; shells 0.26″ thick; flues 0.29″ or 0.3″, when made in rings 24 inches long; rivet-holes drilled, and longitudinal seams double-riveted. This boiler receives certificates from the government inspectors allowing, for 70,000 T. S., a maximum working pressure of 182 pounds, being one sixth the ultimate bursting strain of the shell; but nothing has yet been devised to prevent the operators from exceeding this limit, and 200 to 225 pounds is frequently maintained.

There is always a disposition to do a little more work, particularly with tow-boats. The numerous pier bridges and dams placed in the river in recent years incite preparation to

meet the demands in "running" them, and nothing comes nearer doing this than a "wad" of steam at the proper time. Fifteen years ago, with iron boilers of no defined tensile strength, 160 pounds was "big steam." Now, the facts are as stated.

The evaporative duty of these boilers is about seven pounds of water per pound of coal, and when compared, on a basis of the foot-pounds of work done per pound of fuel, show favorably with any water craft. The demand made upon boilers using the water of these silt-bearing streams is very heavy, and imposes conditions under which other forms, although possibly of better fuel duty, fail in points of service and steadiness.

Much indirect harm is done by a requirement of the supervising inspectors, that a water-space of at least 3 inches should be preserved between the flues and shell, and between the flues themselves. Previous to this enactment, about 1½ inches of space was the practice. The men who made these boilers had always used a 14-inch flue in a 40-inch shell, and they knew no other proportions. As a consequence, in order to comply with the new law, they raised the flues in the shell sufficiently to secure the required 3 inches of water-space, and thereby vastly diminished the steam space, as well as curtailed the surface for the elimination of the steam.

There is one other form of boiler almost as popular as the "double-flued." The shell, 42 inches diameter, contains six 8-inch flues, in two rows of three each, the one flue immediately above the other. This gives easy access to every part for cleaning and repair, and steams very well. One such boiler 18 feet long, 210 square feet heating surface, 20 square feet grate surface, is supplying two engines 10 inches diameter, 48-inch stroke, at an initial pressure of 170 pounds. The engines indicate an average of about 170 horse-power, and fuel consumption is 500 to 600 pounds per hour, or a result of 3 to 3½ pounds of coal per H. P. per hour.

Several cases of compounding have given a better result than this, but always at greater first cost, large additions in weight and cost for maintenance, and have generally been succeeded by direct high-pressure in the next boat built by the same owners.

The large increase in working pressures of late years has

demanded greater strength in the machinery and fastenings, and also in the hull construction, but the increase in weight has not been proportionate to the increased power developed, and the service has thereby been improved.

The changes in valve-gear have not been extensive. The plan shown in Fig. 11 has been introduced, and is meeting with some favor. In this valve-gear the effort has been to retain the good qualities of a "cam" movement and improve the results of its action. In the ordinary "lever" gear, four valves, two receiving and two exhaust, are employed to each engine; two engines attached to a common shaft at 90°; two cams are used to each engine—one full stroke, one cut-off. When the engines are in full gear the full-stroke cam operates four valves, raising one exhaust and one receiving valve at opposite ends of the cylinder at the same moment. This one cam does all the work in both full-gear motions of the engine, and is therefore in its neutral position when the crank is at its dead point; the cut-off is engaged after the full gear has given headway to the boat, and is used only in the forward motion. This arrangement necessarily precludes any cam position securing either an early exhaust opening or early closing of the opposite valve. A partial remedy to the consequent poor action has been found by blocking the exhaust lifters, so as to secure a somewhat earlier exhaust, but likewise a later exhaust closure; so that, with the cam in neutral position and the crank on its dead point, both exhaust-valves are partially open. When in full-gear, a slight "blow through" arises from this condition; but after the cut-off is engaged it disappears, because the opening movement of the cut-off cam is much slower than the full stroke.

Fig. 11 indicates a recent gear, employing two full-stroke cams, one for each motion, and set for the usual lead, etc.; also a cut-off cam to each engine. The drop in the lifter of receiving valves allows the lead of exhaust cam to operate the exhaust valves without affecting the receiving valve until the proper time. The cut-off cam is also advanced, and its cut-off point adjusted to meet the altered position.

In a paper read before the American Society of Mechanical Engineers by the writer of this paper, and from which some of the data herein are taken, an opinion was expressed that the improvement in the navigation of the Western waters

S.S. S. G. REED (Oregon River Boat).
175 feet long, 28 feet beam, 6 feet hold.

of the United States would be found in the adoption of composite-built boats, the frames and sides above the light-draught line being of steel, the bottom and sides, up to the light line, of wood.

Since this opinion was given in the paper named, several boats of this construction have been built, one by the writer, which has been entirely successful in general results, although open for future improvements in detail.

The mistakes, if any, have been in the direction of the use of too heavy steel for the frame construction. It has long been accepted as an axiom by Western boatmen, that a stiff boat would not be so speedy, under the same conditions, as the same boat were she limber, but the results so far obtained by composite construction explode this idea entirely; speeds which have been obtained with the stiff construction being in every case better than with the limber boat.

Reference has been made to the fact that light construction is essential for this class of craft, and that in undertaking to develop an excessive amount of power, in proportion to the displacement or buoyancy of the boat, bad results have been obtained. For this reason the hull construction must be with a large number of dead flat frames in order to preserve buoyancy. On some of the rivers of the Pacific Slope, especially the Oregon and Willamette, boats have been constructed on much better model and easier lines than any on the waters flowing into the Gulf of Mexico.

Fig. 12 represents one of these boats, the "S. G. Reed," and gives some idea of the really fine lines found in them. This practice is possible with them through the use of timber which weighs between 25 and 30 pounds to the cubic foot, while the live-oak used for boat-building on the Ohio and Mississippi rivers and tributaries weighs between 60 and 70 pounds to the cubic foot.

The boat represented in Fig. 12 is very much stiffened by the use of fore-and-aft bulkheads through the hold, there being nine. These bulkheads are not in the way, because the load in this case is carried on the main deck; such a practice with the live-oak would make the boat entirely too deep in minimum draught. The greater first cost for composite-built boats over wooden boats is all that prevents their rapid introduction in the Ohio and Mississippi rivers, but it is to be

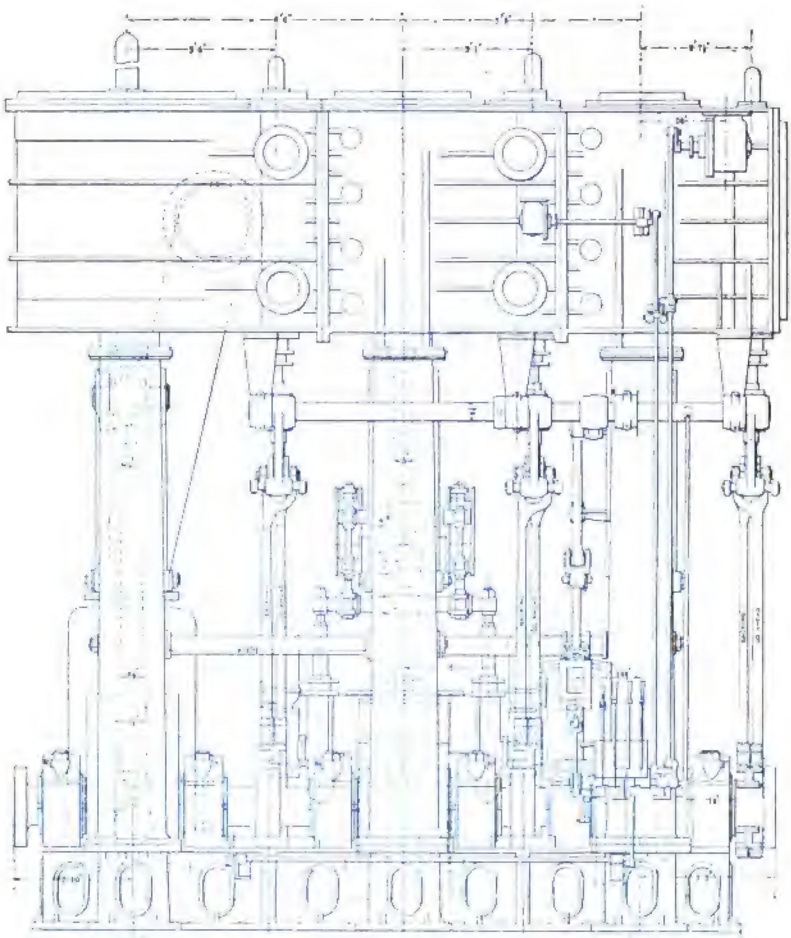


Fig 19

DISCUSSION ON THE CONSTRUCTION OF STEAMBOATS NAVIGATING THE WESTERN WATERS OF THE UNITED STATES.

PROF. JAMES E. DENTON:—As a possibly interesting supplement to Mr. Sweeny's valuable paper, I venture to add the following results of efficiency tests of the propelling machinery of one of the peculiar styles of steamboats to whose discussion the paper is devoted.

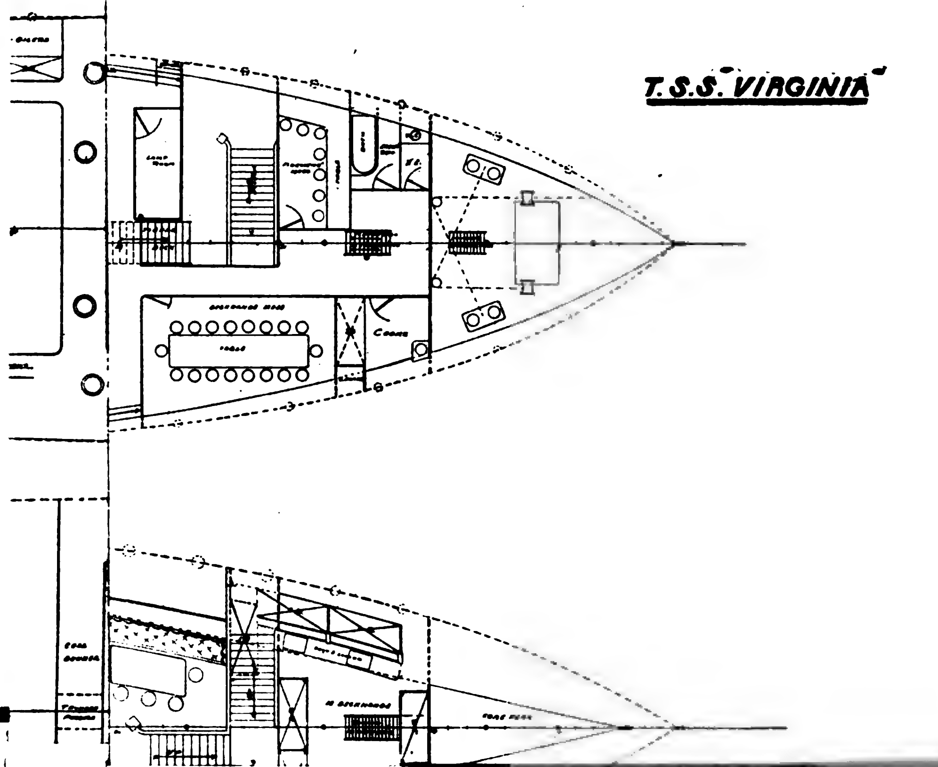
The data were secured by Messrs. Wm. Whigham and C. V. Kerr, graduates of the Class of '88 at the Stevens Institute, during some careful tests conducted by them on a voyage between Pittsburg, Pa., and the mouth of the Red River, La.

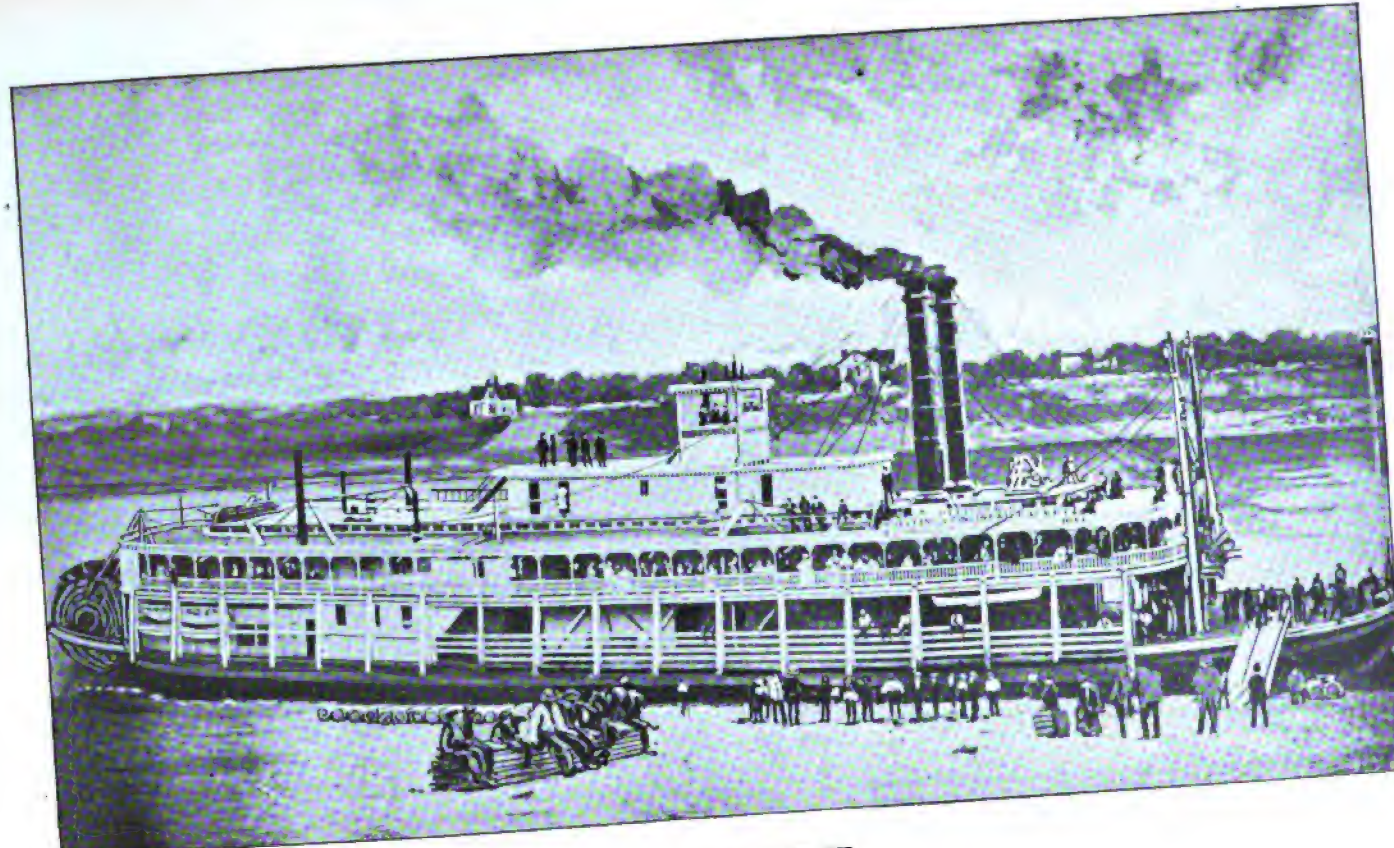
DIMENSIONS TOWBOAT "O'NEIL."

Length of hull, feet	201
Depth of hold, "	8
Width of top of hull, inside guards, feet	38
Diameter of wheel, feet	28
Length " " "	28
Material " "	wood.
Number " " buckets	17
Width " " " feet	3
Dip " " " " loaded	3
Number of cylinders, main engine	2
Diameter " " " " inches	24.5
Stroke " " " " feet	12
Clearance " " " " per cent of piston-displacement	8
Number of boilers	6
Diameter " " inches	47
Length " " feet	28
Number of flues in each boiler	6
Diameter of flues, inches	10
Heating surface, square feet, total	3979
Grate-surface " " "	138
Ratio	28.8

S.S. FLEETWOOD.

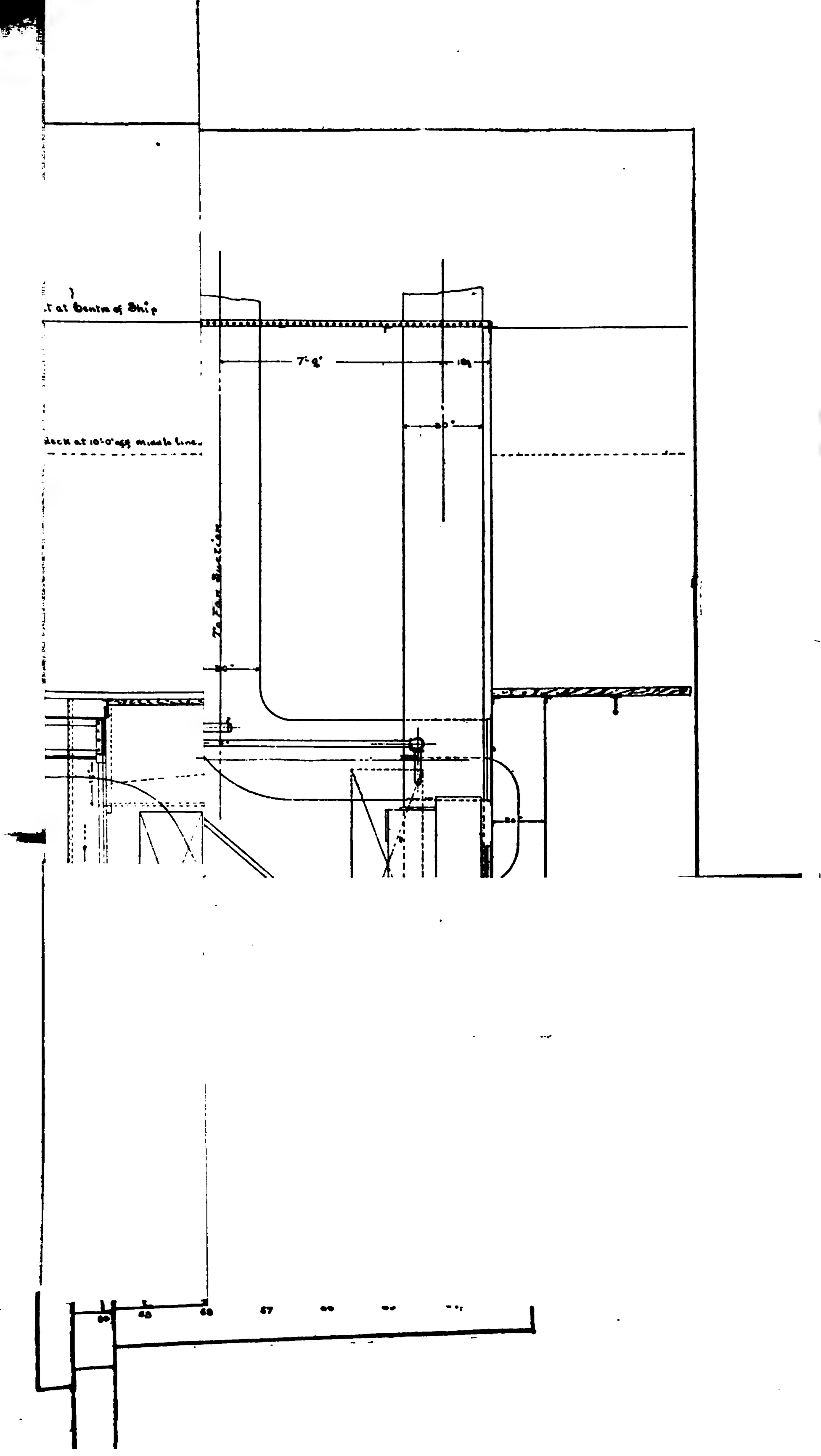
T.S.S. "VIRGINIA"





S.S. HUDSON, 1878.

S.S. HUDSON, 1886.


at Centre of Ship
To Fan Suction

RESULTS OF BOILER-TEST—TOWBOAT "O'NEIL."

	Small steam-jet in stack. Going down stream at 12 revolutions.	Full exhaust in stack. Going up stream at 17 revolutions.
Draught, inches in water	0.6	1.02
Duration, hours	12	16
Boiler-pressure above atmosphere, lbs. per square inch	153	155
Temperature of feed, degrees Fahr	200	211
" " chimney gases, degrees Fahr.	640	824
Fuel	Bituminous slack.	
Fuel consumed per hour per sq. ft. of grate, lbs.	32.5	59.6
Evaporation per lb. of fuel, actual pressure and feed temperature, lbs.	7.57	7.18
Evaporation per lb. of fuel from and at 212° Fahr., lbs.	8.06	7.49
Evaporation per hour per sq. ft. of heating-surface from and at 212° Fahr., lbs.	9.2	14.7

RESULTS OF ENGINE-TEST.

Duration, hours	12
Revolutions per minute	16.88
Cut-off, per cent of stroke	77
Average boiler-pressure above atmosphere, lbs. per square inch	153
Average initial pressure in cylinders, lbs. per square inch	139
" mean effective pressure, " " " "	123
" back-pressure above atmosphere, lbs. per square inch	12
" indicated horse-power, both engines	1384
" steam per hour per horse-power calculated from cards, lbs.	29.6
Average feed-water per hour per horse-power by displacement of feed-pump, lbs.	39.7
Cylinder condensation, per cent of feed-water	26
Coal per hour per horse-power, lbs.	5.56

The feed-pump was single-acting, with outside packed plungers making 18 revolutions per minute. There was no piston leakage, but there may have been a "slip" of possibly 3%, and therefore the water per horse-power may be too large to this extent.

I understand, through a Western correspondent, that the weight of the machinery would be about as follows:

Wheel-shaft and cranks (not including wheel)	16 tons.
Engines and pumps, and supporting timbers	38.5 "
Piping and connections	10 "
Boilers, empty	20 "
Water to fill boilers to average level	23 "
Total	107.5 tons.

These results show that about eleven horse-power are developed per square foot of grate with about 60 lbs. of coal consumption per hour per square foot of grate, and about 13 horse-power per ton of weight of machinery, exclusive of the paddle-wheel. Also, that a horse-power is supplied by 2.7 square feet of heating-surface, and 5.56 lbs. of coal per hour.

In the smooth-water paddle-wheel practice, for fast passenger traffic on the Hudson River and Long Island Sound with walking-beam condensing engines, if the amount of horse-power used on the "O'Neil" was obtained from two engines, they might each have a cylinder about 51″ diameter and 8′ stroke, driving radial paddle-wheels about 25 ft. in diameter at about 25 revolutions, with 25 lbs. steam-pressure, and with cut-off at about one-half stroke and a vacuum of about 27 inches.

Small-size anthracite coal would be consumed at the rate of about 40 lbs. per square foot of grate per hour, with forced draught produced by a fan delivering air under the grate. The engine would use about 25 lbs. of feed-water and about $3\frac{1}{4}$ lbs. of coal per hour per horse-power. The boilers would be of the return tubular internal fire-box type, with about 120 square feet of grate and 3800 feet of heating-surface.

The weight of machinery would be as follows:

Engines, pumps, foundations, wheel-shaft, cranks, piping, and connections (not including wheel)	110	tons.
Boilers, empty	31	"
Water for boilers	33	"
Total	174	tons.

If all the power was obtained from a single walking-beam engine with 50 lbs. of steam, cutting off at one-half with the best vacuum, the minimum size of cylinder would be 48″ in diameter and 10′ stroke, with about 30 revolutions per minute. With the same boilers and the same rate of combustion the total weight of machinery, exclusive of wheel, would be about 160 tons. The coal consumption might, as a minimum, be three pounds per horse-power. We have, therefore, for the Eastern passenger paddle-wheel practice about $11\frac{1}{2}$ H.P. per square foot of grate with 40 lbs. coal consumption per hour; about $8\frac{1}{4}$ H.P. per ton of weight of machinery, exclusive of the paddle-wheels; and about 2.7 sq. ft. of heating-surface per H.P.

To make a fair comparison of weights with the "O'Neil," however, we must use proportions of the walking-beam engines such

that the product of the mean effective pressure, piston area, and stroke will be the same as in the "O'Neil." With 50 lbs. boiler pressure, at half cut-off, the condensing engine will afford 45 lbs. mean effective pressure.

This pressure in two cylinders 51″ × 8′ would make the above product about 10 per cent greater than in the "O'Neil." The weight of the two walking-beam engines would then be about 125 tons, and the boilers filled would weigh about 75 tons, making the total weight of machinery, exclusive of wheels, 200 tons. A single cylinder to cover the same conditions would be 60″ diameter by 12′ stroke, and would give practically the same weight of machinery.

The coal consumption per hour per horse-power would probably be 3.75 lbs., making 130 sq. ft. of grate necessary with a rate of combustion of 40 lbs. Under towboat conditions, or for about 1400 H.P. and 17 revolutions, with equal rotative efforts, the walking-beam practice, therefore, affords 10.8 H.P. per square foot of grate, 7 H.P. per ton of weight of machinery, exclusive of wheels, and one H.P. per 2.75 sq. ft. of heating-surface and 3.75 lbs. of coal per hour.

Both types of engines derive practically the same H.P. from a given grate and boiler, as the low-pressure condensing type consumes less fuel per horse-power in just about the same proportion, 33%, that the Western maximum rate of combustion exceeds the rate used in the Eastern practice. The low-pressure engine weighs about 90% more per H.P. than that of the high-pressure type. The low weight of machinery per H.P. is, of course, the main object of the Western design, and the latter's fitness for Western river service in this respect is clearly recognized by all who study the conditions of this service intelligently. On the other hand when there is sufficient draught of water for the use of low-pressure walking-beam types of engines the saving in fuel of the latter over the Western type of engine, with coal at $3.50 per gross ton, amounts to $48 per day of twelve hours for 1400 horse-power, which affords a saving in the cost of operation many times the interest and depreciation on the difference in the cost of the two styles of machinery.

A question sometimes asked in the East is, Why are condensers not used with the Western river type of engine? No doubt Mr. Sweeny could best answer this; but it may be interesting to note here, that assuming no trouble from the muddy water in fouling the condensers, the weight of an air-pump and jet-condenser of sufficient capacity to create a good vacuum for the case of the "O'Neil" would probably be 25 tons. This represents an increase

of about 25% in the weight of machinery, with a possible increase of power of a given cylinder of only about 10%, so that the total weight of machinery per horse-power would be increased by the addition of a condenser.

COL. E. A. STEVENS:—There is one thing which always struck me the few times I have been on the steamers of the Mississippi, and that is the admirable design of the joiner-work. I think all of us in the East who are concerned in the construction of river or sound vessels can very well take a leaf out of the book of these Western builders. I should judge that the saving in weight in the Mississippi steamers, in what seems to be of equal strength (it looks light to us, but it seems to do the work), would be not less than 15 per cent.

MR. E. PLATT STRATTON:—A few years ago it was my province to visit the Western rivers with an idea of determining what could be done in the matter of getting up some type of engine and boiler to do this work on less weight. I spent some six weeks out there and visited the principal ports of the Western rivers, and it was a subject of surprise not only to myself but to the engineering company I represented in the East to find how economically and with how little weight of material the Western river engineer was developing his power. Many of us are struck with the idea that the single inclined or horizontal river engine in use is a very crude method of engineering, but when we take the pains to figure the amount of coal burned on the square foot of grate-surface, the small cost of the boiler and engines, and the power that is produced per pound of coal, etc., it will astonish most of us.

MR. CHARLES WARD:—Following the line of Mr. Sweeney's most interesting paper on river steamers, I should like to present to the attention of this Congress the peculiarities of a small river steamer I have recently built for the Engineer Corps of the U. S. War Department.

The requirements were a steel hull, 60 feet long, 8 feet beam, 3½ feet depth of hull, which should run on fourteen inches of water and make not less than ten miles. In order to get the lightest machinery, we decided to make a specially designed engine. In order to use a screw of sufficient size to drive the boat without projecting below the line of the bottom of the boat, we resorted to a projection at the rear of the boat over the screw and rudder, forming an inverted pocket or receptacle for the upper portion of the screw, expecting the screw to expel the air from this pocket, and carry solid water therein, so that the screw would work in solid water. The propeller is 24 inches diameter, so that the bottom

being on a line with the bottom of the boat, 14 inches are submerged and 10 inches are above the water when the boat is at rest.

The hull is of steel, and carries a house 30 feet long, the width of the boat. The boiler is Ward launch type, 280 feet heating-surface, 12.3 feet grate; weight, 3800 pounds, including water. The engine is $\frac{''6\frac{1}{2} \text{ and } 13''}{8''}$, of special design, with one valve and one eccentric for both cylinders. Its weight is 1000 pounds. The total displacement of the boat in steaming condition is six and one half tons.

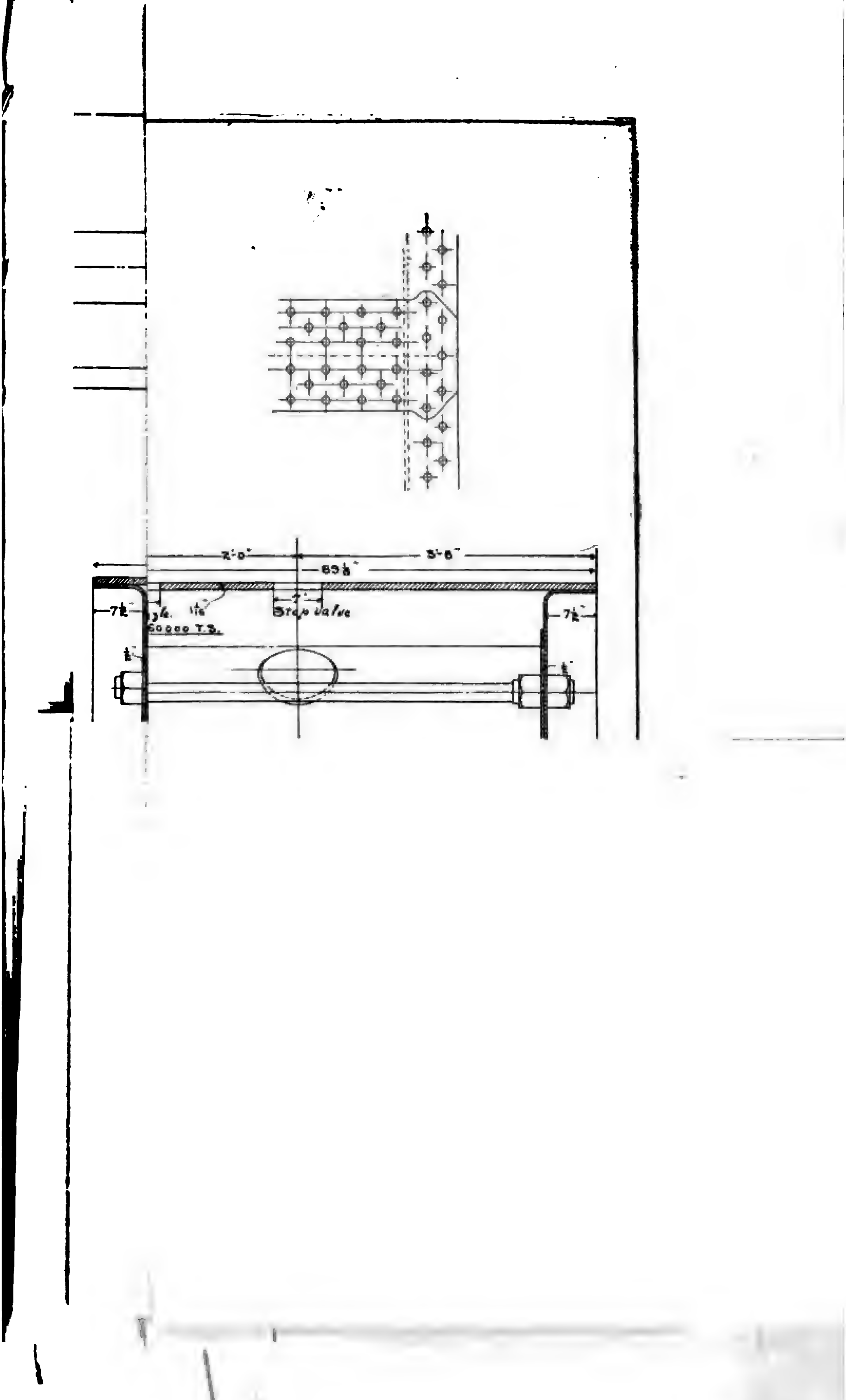
With steam at 150 pounds we made 540 revolutions per minute. and obtained a speed of $13\frac{1}{8}$ miles. The peculiarity of this boat is its extremely light draught, 7 inches forward and 14 inches aft, and the fact that when the boat is at rest $\frac{10}{24}$ of the diameter of the screw is above water. The speed of $13\frac{1}{8}$ miles seemed to indicate that the screw did fairly good work, but the slip of 40 per cent showed too great a loss somewhere. The question therefore arose whether the water in the pocket was solid above the screw. As we had, in order to try several screws, provided two rudder-post tubes reaching from this pocket upward, it was decided to remove the cap of one of them to ascertain the condition of the water around the screw. The boat was fast to the dock; the engine was making about 200 revolutions. Immediately on removing the cap the water spouted up in a solid stream through this tube two feet high; on increasing the speed of the engine to 300 revolutions, the water rose some four or five feet; when speeded up to 400 or 500 revolutions, there was a fountain eight or nine feet high. As this occurred with the boat moored to the dock, the question naturally arose, Would the results be the same if the boat was in free course? This was tried, with the same results. Being unable to get a clear photograph with the boat in motion, we ran her against a pier of the movable dams on the Kanawha River, when a picture was taken showing the same result.

From the height of the fountain it would appear that there was a pressure upwards in the pocket equal to the height of the column of water: if such, however, was the case, it is singular that it does not show itself on the sides of the boat.

Some such form of stern as this would seem to be a remedy for squatting.

I submit drawing of the boat, showing the pocket at the stern.

It was my intention to test a Thornycroft screw of the guide-blade propeller type, working in a tube which, with an elongated



2'-0"
7 1/2"
Stop Valve
60000 T.S.

once the stern of the boat leaves the shore—seems to pick it up and lift it away from the shore. I have seen these boats back up against the current where their bows were stuck on the bank until they would be at right angles to the shore before they would pull away from the shore.

No matter how hard the wind was blowing, our stern-wheel boats could get out and twist around and be gone before lake boats would be ready to start. I should like to have one of these boats working from Van Buren Street to the Fair. The experience we have had in the St. John's River, Lake Monroe, and Lake George, in Florida, has been that our boats fitted that service better than sound boats or that class of boats; they have been speedier, and would get around through the crooked part of St. John's River without any trouble, where you could jump off from the boat at either end.

Mr. Geo. W. Dickie:—There is another question. In the boats we have been discussing, it appears to be the universal practice to use the cam for the cut-off. In the stern-wheel boats on the Pacific coast the cam is very little used, and the cut-off is effected by a wedge working on top of the valve-lever. The valve is operated by the simple eccentric, and another eccentric is introduced to work these sliding wedges. Is that in use on the rivers here? What is the practice in cams?

Mr. Sweeney:—There are perhaps a dozen different devices, giving very variable expansions. The California cut-off has been used. Most of the plans for variable cut-off have the objection that the mechanism frequently fails to work when the engines are reversed; and I know of two cases where they were bodily ejected from a boat, because, landing alongside a wharf-boat, the machinery failed to back and the wharf-boat was sunk. Now the result of using automatic cut-offs on these rivers has been simply this,—that we have got down to a place where we found the boat would make steam. Boats on the river are useless unless they make steam. They want plenty of pressure all the time, and where a variable cut-off has been used, in almost every instance it has been regulated to cut-off at a point where the boilers would generate steam properly, that is, plenty of pressure, and there it has been left. That is why the fixed cam cut-offs have the preference.

Perhaps some day, with the rivers locked and navigated more steadily, more costly fuel and greater necessity for economy in that item, our engineers and owners may be educated to the benefits from a properly used variable cut-off.

Mr. Dickie:—Have any of these river steamers of very light draught been tried with turbine-wheels instead of stern-wheels?

Mr. Roelker:—Referring to the question of backing a boat

off from the bank, I would say: The propeller will probably not do as well as many might think. A propeller has comparatively little power when backing or going ahead while fastened to a stationary point. It gets its power when the boat moves fast through the water in connection with a high number of revolutions. The great advances which have lately been made in obtaining power out of propellers have been made on vessels of high speed. When the vessel is stationary, a propeller gives comparatively little power, even with a high number of revolutions.

MR. SWEENEY:—In reply to Mr. Dickie, I do not know of such a wheel having been tried, nor do I know of feathering-wheels having been tried on stern-wheel boats on the Mississippi River. At one time we started to build steel wheels on stern-wheel boats, because we thought we could get them lighter than wood wheels, and they were originally constructed lighter; but we found in a little while that the ice or drift, or running the wheel on the shore, destroyed it, or bent it so that we had to build it stronger; and even then the wheels were not entirely satisfactory. That resulted in abandoning the steel wheels and going back to the wooden wheels, because presently the steel wheels got heavier than the wooden, and when they were bent would interfere with the use of the wheel until straightened again; while a wooden arm or bucket may be broken out, and the boat goes on about her business until the usual "lay-over" allows repairs to be made. There is no doubt that feathering-wheels would give very much better results as to speed, but I have never been able to get on well with its introduction, because the owners doubt the ability to keep it in repair. As you know, those streams carry with them a great deal of sediment, and that is very liable to make excessive wear. I know of one boat at New Orleans running with feathering-wheels where that has been the objection.

MR. RAYNAL:—Have any twin-screw boats been tried?

MR. SWEENEY:—No, not that I know of.

MR. RAYNAL:—Do you think that the same objections would hold good with twin-screw boats?

MR. SWEENEY:—Yes. Two screws would give twice the trouble that one would.

A MEMBER:—How about snags?

MR. SWEENEY:—They do not bother the wooden wheels, because any "wood butcher" could fix the wheels. The experience has not been great with screws, but so far snags are their deadly enemy.

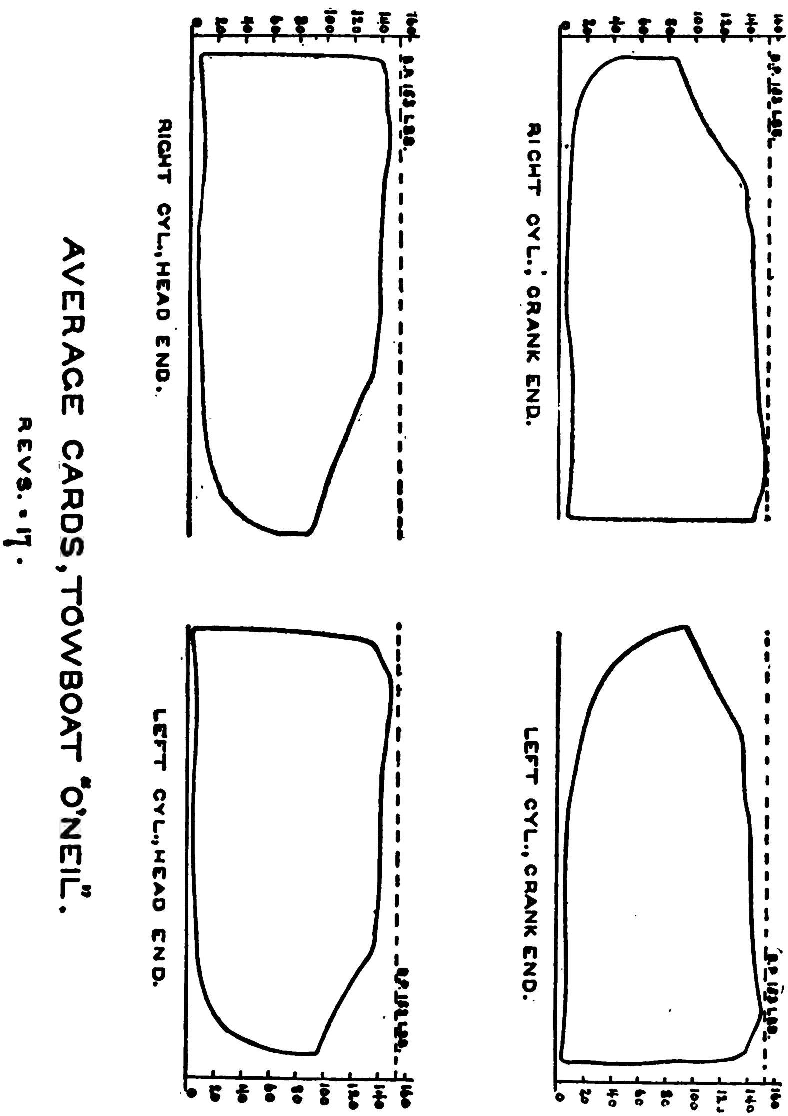
MR. WARD:—I would like to supplement Mr. Sweeney's remarks in regard to these steamers. They do seem most peculiarly

adapted to their work, although they appear ingenious in some parts of their construction, in other parts exceedingly crude. It is not an unusual thing to see a good-sized boat loaded with passengers come swinging around the curves of the river with wonderful rapidity. It is simply marvellous what they will do. They are utterly unstable in their lines, and on such exceedingly light draughts, from 2 feet to 3 and 4 feet,—2 to 3 usually,—that although I have been called upon frequently to see if some other means could not be devised which could give better results, invariably I come back to the conclusion that there is nothing like the stern-wheel boat for our rivers. They will work in spite of ice, rocks, and all other obstructions which are likely to be found in the rivers, and they certainly do some very satisfactory work. The only strange thing is that, with our knowledge of triple-expansion and compound engines, they do not seem to gain a foothold. When everything is taken into consideration, it is marvellous how well the boats are adapted to the conditions of the case.

With regard to the use of twin-screws, I am familiar with one case where they were used and failed; but I must say that the failure of that particular propeller was probably due to the way in which it was built, and not to the fact of twin-screws being inserted. I think the day is not far distant when we shall have some approved and economical method applicable to the boats for low draught in the river. I think it lies in the direction of twin-screw boats. In the Sweeney boats there were four high-pressure cylinders. When we can get a compound engine working with the economy that is well known to all of us, it does seem marvellous that a man at this age should put in four high-pressure engines, perhaps 14 inches in diameter. With a Scotch boiler placed therein we would have everlasting trouble; there has never been steam enough; we have to give added steam; and I do think that the failure is not to be charged to the unfitness of twin-screws, but rather to the arrangement of the screws and machinery.

Mr. Dickie:—It might be interesting for me to mention that we have built some stern-wheel boats of great power out on the Pacific coast. I think the largest that we have built have 28-inch cylinders with 8-feet stroke, and with a variable cut-off. They have worked with great satisfaction, and with considerable economy. I have some data myself as to the economy of these engines, and I am sorry that I did not know that this subject would come up, or I would have brought them with me.

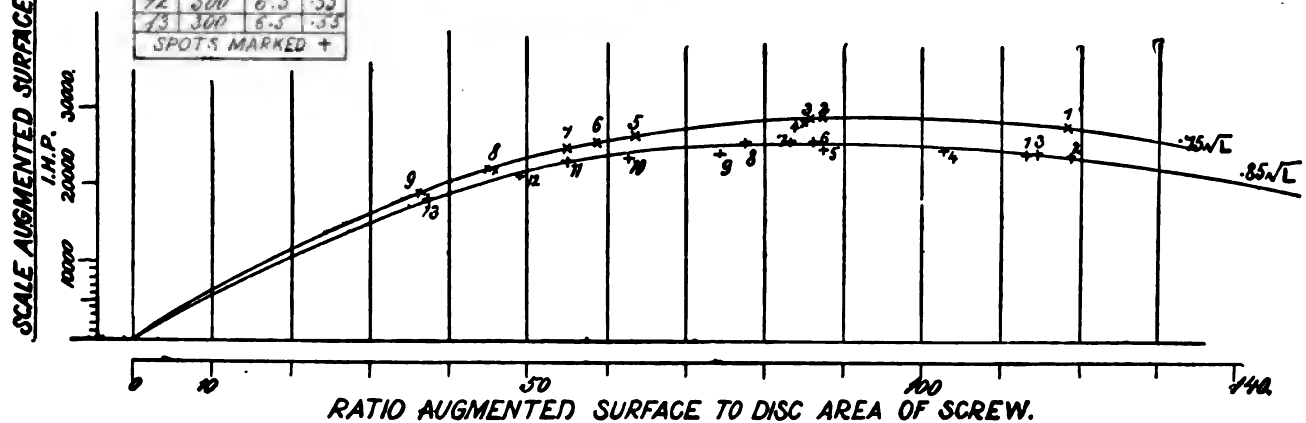
This matter of steam-navigation on the great rivers and great lakes is a thing of very great interest to me, and I am delighted with the shape that the discussion has taken in regard to it.

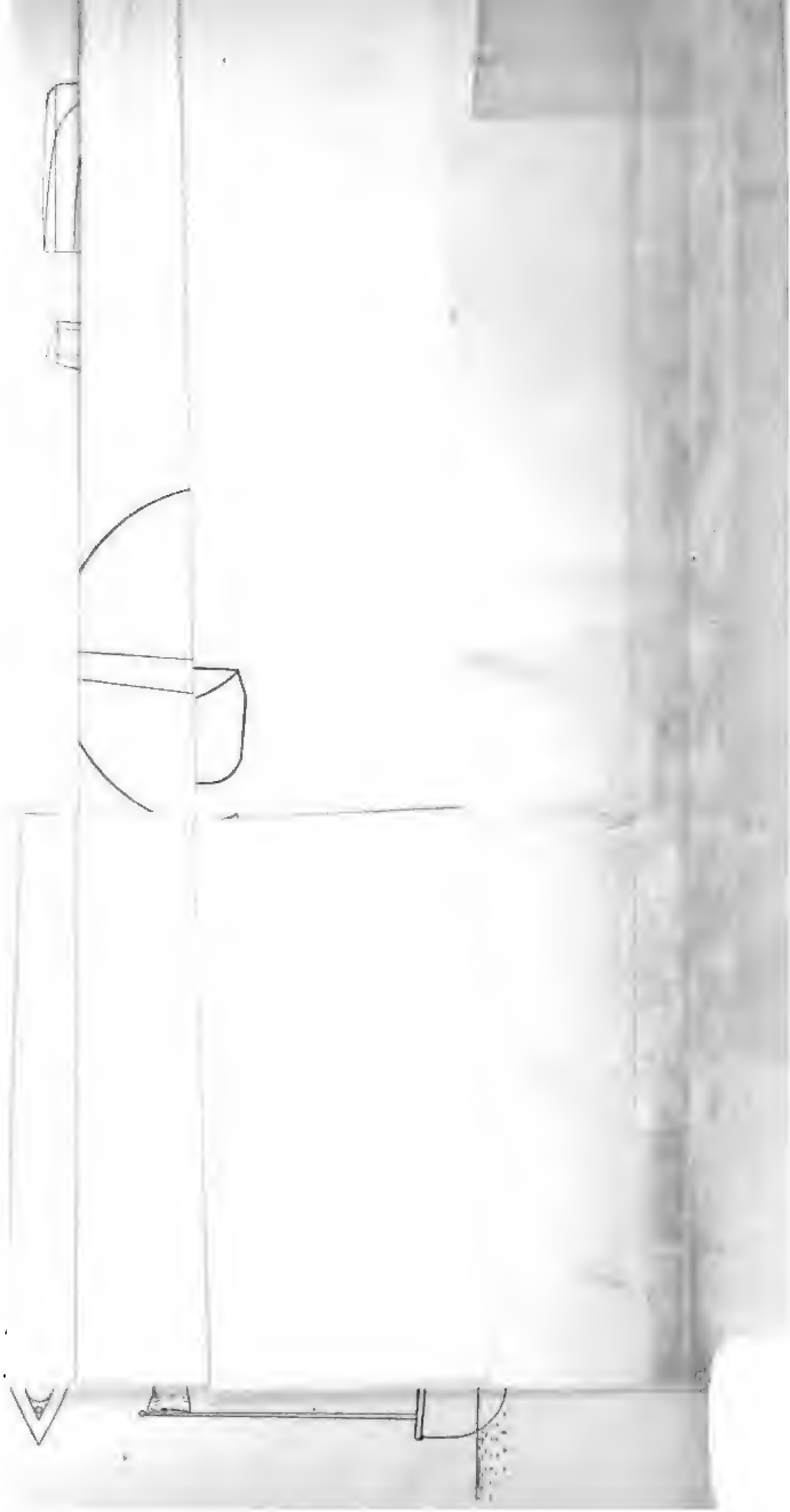

AVERAGE CARDS, TOWBOAT "O'NEIL".
REVS. = 17.
RIGHT CYL., HEAD END.
RIGHT CYL., CRANK END.
LEFT CYL., HEAD END.
LEFT CYL., CRANK END.
B.P. 153 LBS.
0
20
40
60
80
100
120
140
160

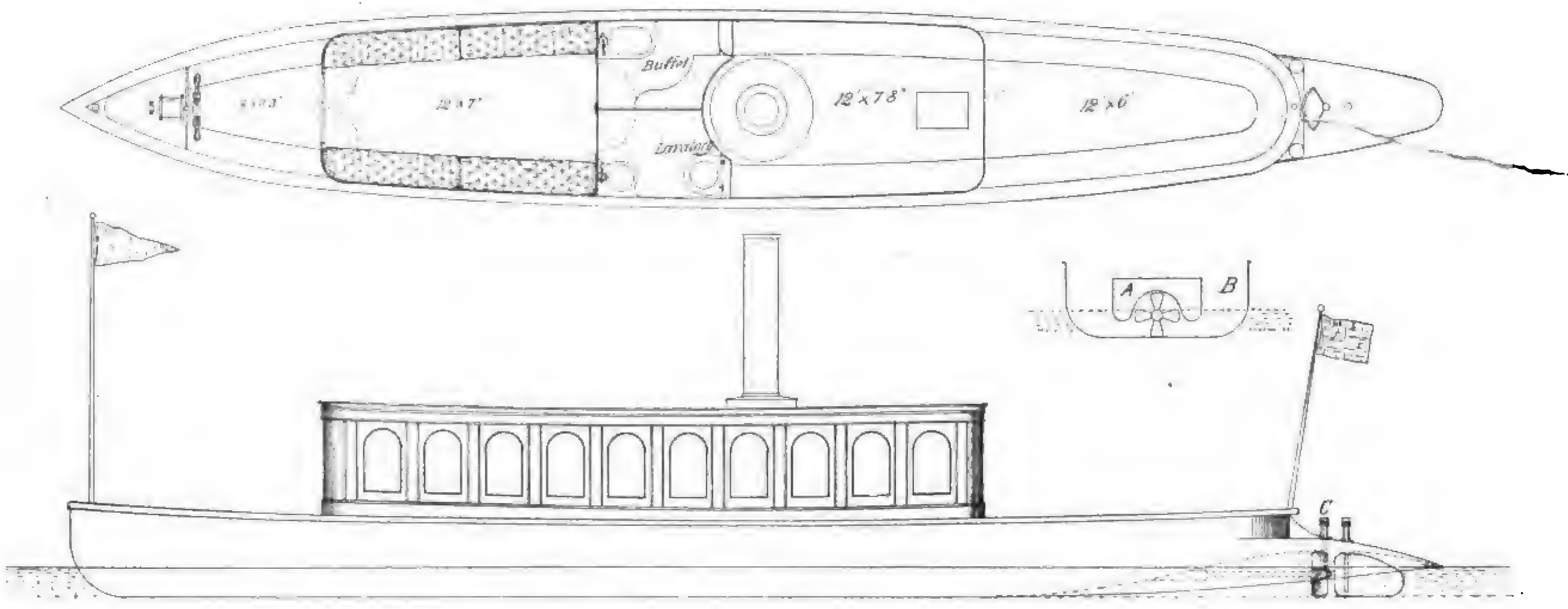
SPEEDS OF .86√L			
Nº	LENGTH	LENGTH / BEAM	PRIS. COEF.
1	220	7.2	.65
2	431	8.6	6.4
3	225	7.5	6.
4	300	8.8	.655
5	418	8.14	.655
6	313.6	8.15	.655
7	500	8.8	.655
8	343.5	8.14	.655
9	265	6.50	.60
10	250	6.75	.61
11	216	7.5	.61
12	300	6.5	.55
13	300	6.5	.55
SPOTS MARKED +			

SPEEDS OF .75√L			
Nº	LENGTH	LENGTH / BEAM	PRIS. COEF.
1	431	8.6	.64
2	500	8.8	.655
3	315.5	8.15	.658
4	438	9.1	.656
5	250	6.75	.610
6	300	6.5	.550
7	216	7.5	.610
8	300	6.5	.55
9	300	6.5	.55
SPOTS MARKED ×			

DIAGRAM SHEWING VALUES of $\frac{\text{AUGMENTED SURFACE} \times V^3}{\text{I.H.P.}}$ IN RELATION TO THE RATIO OF AUGMENTED SURFACE TO DISC AREA OF SCREW: ALL SCREWS BEING REDUCED TO ONE STANDARD OF PITCH AND SURFACE RATIO.







Buffet
Lavatory
12'x7'8"
12'x6'
12'x7'
A
B
C

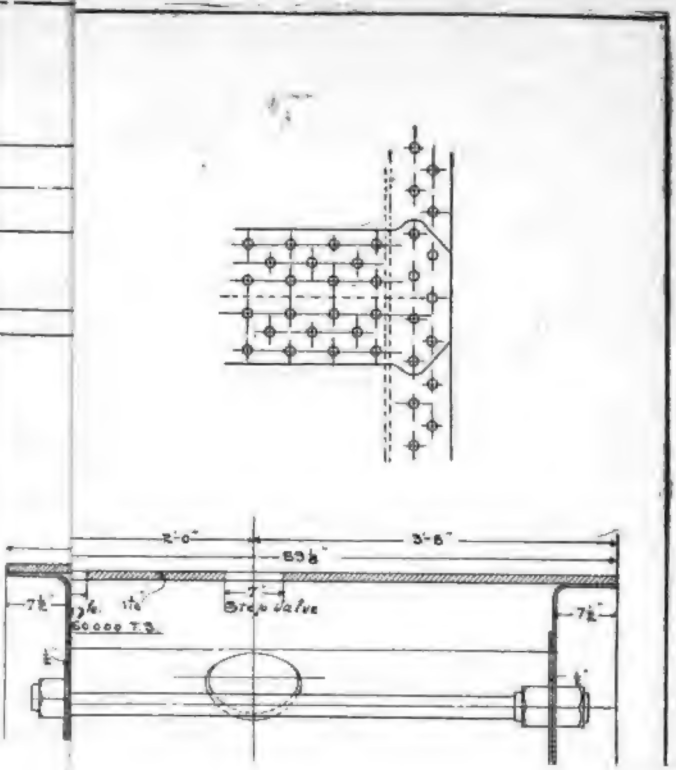
XXXIX.

GOVERNMENT INSPECTION OF MERCHANT STEAMERS AND THE INFLUENCE THEREON OF THE RULES OF THE REGISTRATION SOCIETIES.

BY E. PLATT STRATTON, ESQ.,

Chief Engineer Surveyor to the Record of American and Foreign Shipping.

THE necessity of government control over American steam vessels was recognized by Congress immediately after the first successful application of steam to navigation, and as early as March 12, 1812, we find enacted what is now Chapter 40 of the Revised Statutes, entitled "An Act for the Enrolling and Licensing of Steamboats." By the Act of March 3, 1825, the provisions of that Act were extended to vessels owned by incorporated companies; and this was followed by the Act of July 17, 1838, providing for the better security of the lives of passengers on steam vessels. This seems to be the first Act of Congress providing for the actual inspection of vessels propelled in whole or in part by steam. By this statute it is made the duty of "the district judge of the United States within whose district any ports of entry or delivery" are situated, to appoint, on application of the master or owner, "one or more persons skilled and competent to make inspections of the boilers and machinery of such vessels, to inspect the same." The law of 1838 was first amended by the Act of March 3, 1843, which is chiefly remarkable in that it exempted from inspection all vessels propelled by sails and Ericsson's propeller and used exclusively in carrying freight on the Great Lakes; it also authorized the "Secretary of the Navy to appoint a board of examiners, to consist of three persons of thorough knowledge as to the structure and use of the steam-


2'-0"
3'-6"
7"
Stop valve
60000 T.S.
7½"
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inspect the hull or boilers of a steam vessel under a law supposed to be enacted for the protection of human life, and to pass upon the stability and seaworthiness of all classes of steam vessels in the interest of the travelling public?

In many respects the administration of the Steamboat Inspection Service under the present laws is most remarkable. Its officers possess legislative, executive, and judicial functions. Under the first head its Board of Supervising Inspectors make and pass rules which, when approved by the Secretary of the Treasury, have, under Section 4405 of the Revised Statutes, the full force of law. Then the presiding officer of the Board, in the person of the Supervising Inspector-General, by Section 4403, superintends, under the direction of the Secretary of the Treasury, the administration of the entire service and the execution of the rules which he assists in enacting. Under the judicial function, by Section 4450, the local board of inspectors have authority to investigate within their respective districts all acts of incompetency or misconduct, and have power to summon before them witnesses and to compel their attendance by compulsory process; and under Section 4452, the same powers are conferred on supervising inspectors. The practical effect of this is to enable such officers to investigate any accident that may have occurred in consequence of their own neglect or inefficiency. Thus, if a boiler inspected by one of them subsequently explodes, it becomes their duty to investigate the matter, and it was but fair to expect, what experience has since shown to be the case, that the investigators rarely attribute such accidents or explosions to their own inefficiency or shortcomings. The law, administered under such conditions, becomes a mockery to the government and a delusion to the public.

Is it not somewhat to be wondered at that the Government, after having had to deal with steamboat inspection and the laws governing it for over fifty-five years, has not arrived at a better system?

Section 4404 provides for the appointment of ten supervising inspectors, each to be selected for his knowledge, skill, and practical experience in the uses of steam for navigation, and to be a competent judge of the character and qualities of steam vessels, and of all parts of the machinery

employed in steaming. Under such requirements it might be supposed that ample provision is made for skilful officers with proper qualifications for this branch of the service. Such, however, is not the case; for, in the first place, the compensation is inadequate; and secondly, the tenure of office is entirely subject to all the political changes known to our system; it is not a question of how well these men, when appointed, can perform their duties without fear or favor, but how long their political "pull" can be utilized to keep them in place. Under such conditions the Steamboat Inspection Service is a hindrance, rather than an assistance, to the development of our merchant marine. Men have been appointed to these positions who could not draw the simplest specification for the building or repairing of a steam vessel, much less define the size, or proportion, or character of the parts of an engine, boiler, condenser or pump, or compute the proportions that the size of one should bear to the other; they are appointed under our system simply on political attainments, and skilful mechanical engineers, practical shipbuilders, or marine architects are seldom, if ever, enough of politicians to secure the senatorial or congressional aid necessary to obtain such places, much less retain them long enough to make the service feel the benefit of their knowledge and experience.

Section 4430, R. S., provides that "every iron or steel plate used in the construction of steamboat boilers which shall be subject to a tensile strain shall be inspected in such manner as shall be prescribed by the Board of Supervising Inspectors and approved by the Secretary of the Treasury; . . . and no iron or steel plate shall be used in the construction of such boilers which has not been inspected and approved under these rules." This makes it obligatory that the boilers of all steam vessels built in this country shall meet the requirements of the rules that may be passed by this Board, which, as has already been said, is composed of members, not selected for what they may know or have had to do with the design, construction, or management of steam vessels, their engines, boilers and machinery, or the uses of steam in navigation, but too frequently for how little they know of the details of such matters. If a demonstration of this were needed, it is conclusively furnished by reference to the Annual Proceedings of the Board of Supervising Inspectors for

1878, where, at page 20, a report of a special committee composed of the head of the service and four supervising inspectors recommends that "the Inspectors cause two pieces of material to be taken from each sheet to be tested," . . . and that piece showing the greatest tensile strain shall be held to be the tensile strain of the plate from which the test piece was taken." The report was adopted, and the Secretary of the Treasury was induced to approve it (see page 39, Proceedings of 1878), and as, under Section 4405, R. S., such rules "when approved by the Secretary shall have the force of law," this rule really became a legalized method for the destruction of human life.

Under the requirements of Section 4430 of the Revised Statutes, the Board of Supervising Inspectors has also framed a rule which requires all sample pieces of steel or iron plate to be especially prepared for test of such shape and in such a manner that the point of fracture will be confined to a very short and limited section. This has the effect of giving a breaking strength in excess of what it would be if the strain were extended over a test piece of greater length and wider cross-section. In demonstration of this fact there is submitted the following schedule of twelve test-pieces of marine-boiler steel $1\frac{9}{16}$ in. thickness made on the 2d of March last at the Wellman Iron and Steel Company's Works, Thurlow, Pa.; six of the pieces were of the usual test-piece shape and size, that is, 8″ long between the shoulders of the sample, the other six being prepared as required by the rules of the Board of Supervising Inspectors, all of the material being taken from the product of two heats.

It will be seen that the samples prepared in accordance with the Board's rules showed from 37.4 per cent to 23.6 per cent more tensile strength than the 8″ samples prepared in the usual way, or an average of 27.2 per cent of variation in the two methods of preparing the material. It is hardly necessary to state that this method of testing boiler plate is largely in the interest of the boiler-plate manufacturers, and probably at their suggestion, for they held a meeting at the Continental Hotel, Philadelphia, January 12, 1878, at the request of the Supervising Inspector General, to discuss the matter, and twelve days later the Board of Supervising Inspectors not only adopted the form of test piece which gives

TESTING-MACHINE RECORD, WELLMAN IRON AND STEEL COMPANY.

Report of Tests of $1\frac{9}{16}''$ Plates for Marine-Boiler Steel.

Test No.	Heat No.	Date	Marks	Description.	Dimensions of Test Piece. Width, In.	Dimensions of Test Piece. Thickness, In.	Dimensions of Test Piece. Area, Sq. In.	Area, Least Section after Breaking, Sq. In.	Original Length between Shoulders, In.	Length after Breaking, In.	Elastic Limit in Lbs.	Elastic Limit in Lbs. per Sq. In.	Breaking Strain in Lbs.	Ultimate Strength in Lbs. per Sq. In.	Reduction of Area in Per Cent of Original Area.	Final Elongation in Per Cent of Original Length.	Greater Apparent Strength of Short Test Piece in Per Cent of Strength of Long Test Piece.	Appearance of Fracture.	Remarks.
30919	2346	March 2, 1898.	1	15″ ingot	.303	1.542	.4672	.2704	1	......	......	......	85000	74920	42.12	.....	37.4	cup silky	
30918	2346		1	15″ "	1.146	1.546	1.771	.8981	8	10.620	62900	35520	96500	54490	49.28	32.750		" "	
31447	2304		1	20″ "	.275	1.544	.4246	.2335	1	.. ..	.....	......	28500	67120	45.01	......	23.6	" "	
31448	2364		1	20″ "	1.157	1.547	1.790	.8790	8	10.340	64000	35760	96900	54130	50.89	29.250		irreg. "	
31659	2364		2	20″ "	.240	1.547	.3713	.2085	1	......	.. ..	......	25600	68940	43.85	......	25.7	" "	
31656	2364		2	20″ "	1.048	1.545	1.619	.8132	8	10.230	55900	34530	88700	54790	49.77	27.875		" "	Average = 27.2%
31660	2364		3	20″ "	.252	1.550	.3906	.2121	1	......	......	....	26700	68360	45.72	....	25.3	" "	
31657	2364		3	20″ "	1.148	1.546	1.775	.8176	8	10.720	60200	33920	96800	54540	53.94	34.000		" "	
31661	2364		4	20″ "	.260	1.547	.4022	.2529	1	......	.....	......	27400	68130	37.12	...	25.2	" "	
31658	2364		4	20″ "	1.055	1.546	1.631	.7612	8	10.350	57800	35410	88700	54380	53.33	29.875		" "	
31662	2364		5	20″ "	.265	1.547	.4099	.2529	1	......	......	......	28300	69040	38.30	......	26.4	" "	
31659	2364		5	20″ "	1.157	1.545	1.788	.8127	8	10.350	62000	34680	97600	54600	54.54	29.375		" "	

such a deceptive and erroneous tensile strength, and leads to dangerous construction, but provided that the test piece showing the greatest strength should be held to show the strength of the plate from which the piece was taken.

As a single example of the manner in which some of the boiler inspection of the service is conducted, the following may be cited: A tugboat purchased by the Navy Department about two years ago was found to have a boiler whose longitudinal seams, owing to improper spacing and too great diameter of rivets, gave only 60 per cent of the strength of sheets. If such cases are frequent, something should be done to overcome the apparent lack of skill in the service.

In the matter of the inspection of hulls, the conditions are in no way more satisfactory, since there are many steamboats that are allowed to run, some of them carrying large numbers of passengers, which are marked or classed so low by insurance inspectors that reliable companies will not insure them. The service has no rules for the construction of hulls of either wood, iron, or steel vessels, and does not require the material of the two latter to be tested, either chemically or physically, before it enters into the ship. It has no requirement for cementing or otherwise preserving the internal portions of such vessels, or for their preservation against deterioration. The failure to provide in any way for the installation of electric light and power apparatus on shipboard justifies the assertion that the law is not up with the progress that has been made in ship construction and marine engineering. It is not, however, within the scope of this paper to analyze or expatiate upon all the defects of omission in the law, or the acts of commission under it. It is, however, proper to mention the absence of any provision for the inspection of naphtha launches. There are probably two thousand of such boats in use in the United States, using naphtha not only as fuel, but also in a vaporized form as a means of motive power. Neither the hulls nor machinery of such craft are required to be inspected, nor are their officers required to be examined or licensed; the loss of life in consequence has already been considerable, and the rapidity with which their numbers have increased should long ago have resulted in the formulation of rules upon the subject. It is also deemed proper to say that despite the evident defects in the present system of inspec-

tion, no more efficient or satisfactory enactment seems probable on the part of the government until the creation of a Department of Commerce to deal with the numerous commercial matters now administered by the Secretary of the Treasury, who can have but little disposition and less time to deal with them.

To correct some of the shortcomings of the present Steamboat Laws, the American delegates to the International Marine Conference found it necessary to recommend that the existing inspection rules should be revised by *experts*, and that new rules be formulated if necessary. The Secretary of the Treasury, recognizing the force of such a recommendation emanating from such a source, convened a board of five experts, to whom he referred the matter of such a revision. It is a strong official commentary on the inefficiency of the system of appointing supervising inspectors that none of the members of this board were selected from their ranks. The gentlemen designated as members of the board studiously applied themselves to the task assigned, and placed themselves in communication with most of the leading marine organizations of the country, and finally submitted to the Secretary of the Treasury the result of their labors, in the form of a bill proposed for enactment by Congress. This bill was introduced by Senator Frye of Maine, the Chairman of the Senate Committee on Commerce, in January, 1892, and entitled "A Bill to amend certain sections of Title Fifty-two of the Revised Statutes of the United States, and to carry into effect certain recommendations of the United States delegates to the International Marine Conference." The failure of this bill to become a law seems not to be an unmixed evil, for some of its provisions are clearly unwise, owing probably to the fact that the experts felt called upon to carry out the recommendations of the Conference, some of which had been made in a too general form.

The American people have seldom failed to ultimately solve problems to which they have resolutely addressed themselves, and the writer's wish may be father to his thought that the next great national undertaking which they will solve will be the rehabilitating of American commerce on the sea, by which American iron and steel manufacturers will find an increased demand for their productions, and at the same time,

and through the natural agency of commerce, seek out and develop new fields for the consumption of the productions of our manufacturers and soil. This, too, should be one of the functions of a proposed Department of Commerce, already referred to, under which should be placed the Revenue Marine, the Life-Saving and Steamboat Inspection Service, the Lighthouse establishment and Marine Hospital, and all matters relating to the Bureau of Navigation. When such a department is established, and not until then, will American commercial matters receive the attention at the hands of our government that their importance demands.

It is a difficult matter to define the point at which the rights and privileges of private citizens or business corporations leave off, and that at which the State or national governments should assert themselves in fixing laws and rules compiled under delegated authority and not by Congress itself for supervision over property owned and operated by private citizens, or to determine how far or to what extent the national government may exercise its prerogatives, constitutionally, over the business and property of the individual citizen or corporate institution, as it does in the case of steam-vessel property. There is no question, however, that the national government has under the Constitution the sole right to legislate in relation to matters of commerce, and that under this power it may properly institute governmental inspection in order to provide for the better safety of human life on shipboard. This, it is conceded, is what Congress has endeavored to do; and the defects which have been mentioned are due to the administration of the law rather than to its inadequacy.

It has seemed impossible to treat of the subject of the system of inspecting merchant vessels without pointing out the abuses requiring remedy. Such remedies do not yet seem to be in sight, and, regrettable as it may seem, it is certainly true that if the travelling public had to depend for their protection upon the official inspections they would too frequently find that they had leaned upon broken reeds. Their chief protection, however, comes not from such official inspection, but from the unofficial and more thorough inspections made by the various classification societies established by commercial nations in the interest of their shipping and for the pur-

pose of assisting the merchant to obtain an efficient vessel for his intended trade, to guarantee the vessel herself a reputation commensurate with her efficiency, and to assure to her owner and charterer a status in the insurance world that will justify the taking of the vessel as a risk at the lowest rates of premium. This relation of ship-classification to the business of ship-owner, merchant, and underwriter dates back to the sixteenth century. In fact, there are many points that strongly tend to establish the fact that under the Hanseatic league, as early as 1241, provision was made for the survey and classification of vessels engaged in ocean navigation, although it is believed that ship survey and classification was not established on a business basis until after the establishment of Lloyd's coffee-house in London in 1668. This was virtually the beginning by which the insurance rates of England were established in the interest of underwriting clubs, which congregated at the celebrated "café" where information as to the character and condition of all sea-going craft was reliably collected for the benefit of its patrons. These circumstances gave rise to Lloyd's British Ship Survey and Classification. This organization should not, however, be confounded with "Lloyd's English Insurance Exchange," which collects data relating to vessels' mishaps and gathers information valuable in underwriting, and of which most marine underwriters of England are members.

In America matters relating to ship-classification are chiefly conducted under the auspices of the Boards of Marine Underwriters of New York Boston, Philadelphia, New Orleans, and San Francisco, the first of which seems to have been chiefly instrumental in harmonizing the varied interests connected with ship construction and under whose approval the first American Register of Ship-Classification was published, in 1858, to be followed in 1859 by another called "The American Lloyds." These two Registers of Shipping continued to compete for business for several years, until they ran the matter of ship-classification so low in character that the underwriting community lost confidence in both of them. This resulted in the underwriters, through the American Shipmasters' Association, establishing in 1867 the Record of American and Foreign Shipping, to which the two former Registers ultimately quit the field. Under the system adopted by the

American Shipmasters' Association and its rules for the construction and classification of vessels, as published in the Record of American and Foreign Shipping, whether built of iron, steel, or wood, not less than 2400 American sea-going vessels now stand classed and rated, which equals fully 90 per cent of all the sea-going vessels built in the United States within the past 25 years. To these vessels the government inspection is of little importance, for, if the requirements of the classification society are complied with, it assumes the responsibility of the supervision of a vessel, her engines, boilers, tackle and apparel, from the time that her plans are approved by it until her condition is such that she has passed beyond reasonable or profitable repair, and is therefore unseaworthy and no longer entitled to confidence of owners, shippers, and underwriters in the transportation of dry or perishable merchandise. Then, and not until then, does she pass beyond the care and supervision of the classification society. Thus the defects and omissions of governmental inspection are supplied, and much of its work is done, by the classification associations. Such associations are steadily increasing in importance in the commercial world, while governmental systems of inspection are becoming of less moment. The logical end of this state of affairs is plain, and it is to be hoped that it is not far off, and that the next amendment of our statutes looking to better methods of preventing loss of life at sea shall provide for a governmental supervision over the affairs of the classification societies, which shall in turn furnish experienced and competent inspectors, to be paid at rates determined by commercial usages, and not by arbitrary enactments, and who shall from time to time examine, inspect, and rate vessels, not after the spasmodic and perfunctory style of the present official inspection, but so frequently, carefully and thoroughly as to afford adequate protection, not only to the vast interests concentrated in our water-borne commerce, but to the thousands of human beings whose safety is dependent upon inspections now too frequently carried on in a way of which the public little dreams.

XL.

REVIEW OF SOME OF THE RULES ENFORCED FOR THE CONSTRUCTION OF STEAM-BOILERS.

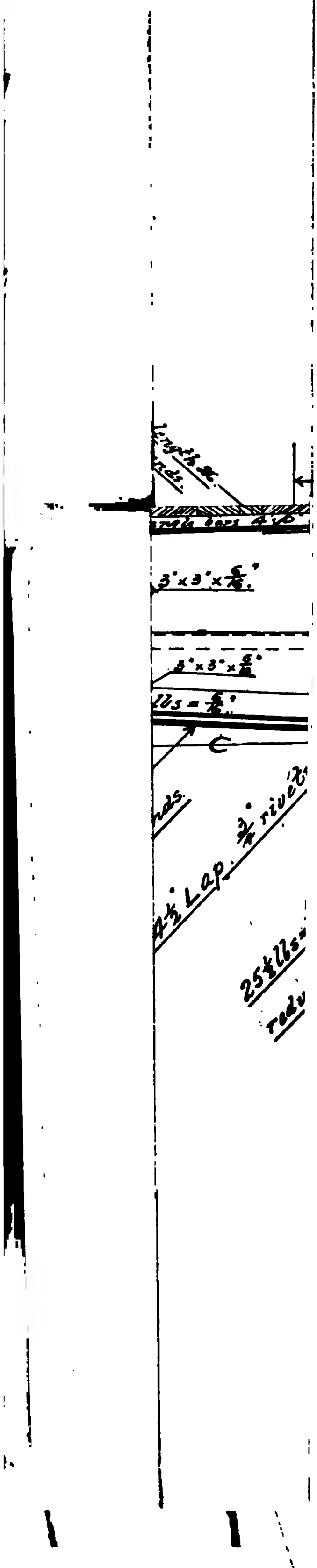
By NELSON FOLEY, Esq.,

Resident Technical Director, Hawthorn-Guppy Engineering Works, Naples; Member of the Institution of Naval Architects, Institution of Mechanical Engineers, and the North-East Coast Institution of Engineers and Shipbuilders.

As steam-boilers are at present, and are likely to be for some time to come, the principal agents at our disposal for converting the energy stored in solid fuels into mechanical work, it is undoubtedly right, and well becomes us on occasions like the present, to review the rules enforced by the principal controlling bodies which affect their construction, and to obtain the opinions on the same of those well qualified to speak.

In passing boiler rules in review, and having opinions expressed by engineers of widely different experience and even nationality, of course it cannot be supposed that any direct result could be the outcome; but surely the deliberations of a body such as this Congress (at any rate if the opinions are at all unanimous) must have some influence in the long-run at the committee meetings of those who from time to time have to revise the rules at present in force.

No matter how we look at it, the subject is of gigantic importance: the commercial life of nations may be said to depend largely upon steam-boilers. It therefore behooves us to see that the subject is so fully studied and its points and side issues so well grasped, that we may have the greatest possible security for life and limb, and at the same time not place an unnecessary check upon the development of steam machinery


4½" Lap.

load on the flat surfaces, or injuries of like nature; disturbance of calking, or other movement.

It therefore comes to this, that a ratio should be fixed on some sound basis, if possible, between the ultimate calculated strength of the joint (when the joint is in question) and the hydraulic proof: in the case of screw stays, assuming that permanent dishing means enlargement of the holes, it remains for us to fix the proof load so as to insure the plates returning to their original state. For the sake of fixing ideas, let us confine ourselves to the question of joints subject to tension. The question is a very complicated one, and one requiring much investigation. The slipping or moving point depends on the class of joint—whether machine or hand riveted, and upon the pressure on the surface of the rivets, leaving out of account the actual section to be sheared.

From the scanty information at hand, I should say that no riveted joint should be stressed to more than 45% of its ultimate calculated breaking stress during a proof load, and possibly 35% or 40% would be much more judicious; for the sake of argument, let us say 30% for lap-joints and 35% for double butt as within the treacherous limit.

It is only fair to say, however, that certain experiments made by Mr. Kirkaldy on treble-riveted joints of mild steel do not seem to corroborate the low slipping points to which I have alluded, judging by the recorded elastic limits of the joints; and it is therefore evident, that, in order to obtain data for the foundation of a rule for proof pressure, much research and possibly further experiments would be necessary, especially if the services and experience of such an expert as the gentleman just named were not obtained.

Having established this ratio, it remains for us to fix some relation or ratio between the proof load and working pressure; and finally, for the sake of convenience, to reduce our results to a relation or ratio, between working pressure and ultimate calculated breaking stress, commonly called the factor of safety. To save confusion, we shall here adhere to what is usually intended to be expressed by the term factor of safety, namely, the ultimate calculated breaking strength divided by the working pressure.

Hydraulic Tests and Factors of Safety.—There are two ways of fixing what we require: one, to establish a definite ratio be-

tween the working pressure and proof load; the other, to have a constant number of pounds pressure between the two. The former is the usual method; the latter was the method adopted by the late Mr. Richard Sennet, acting for the British Admiralty.

Mr. Sennet chose 90 lbs. as the definite constant number of pounds to be added to the working pressure for arriving at the proof pressure. It may further be added in passing, that the proof stress was fixed at $\frac{4}{5}$ of the ultimate calculated breaking stress of the shell; this ratio being based on the limit of elasticity of the material, instead of on the movement of the joints and disturbance of calking.

For boilers of a pressure within certain limits, Mr. Sennet's arbitrary constant, 90 lbs., would meet ordinary requirements, but no rule can be satisfactory which is inconsistent.

Suppose, for instance, we have a boiler of 30 lbs. pressure: no one would ever think of testing it to 90 lbs. above that, nor would it be fair to do so. Suppose, on the other hand, we wished to work at 1000 lbs.: 90 lbs. would probably be considered too close a margin.

An increase of an atmosphere is a large amount for a boiler working at a low pressure, but it becomes little thought of, and is much more likely to take place, where the total range of pressure is great. While running forced-draught trials, for instance, it is a common occurrence, especially in torpedo-boats, to see the pressure rise considerably above the loaded pressure: it would appear that occasionally the proper action of the safety-valves is interfered with by these getting choked with water. In the case of forced draught, it is well to have a considerable margin in the eventuality of the engines being suddenly stopped when everything is pressed to the utmost.

If we fix a definite ratio between the working pressure and proof pressure, we are also led to an unsatisfactory state of matters where we go to extremes; 60 lbs. would probably be granted as a satisfactory proof pressure for a boiler to be worked at 30, but 300 seems, on the other hand, most unreasonably high for a working pressure of 150.

It seems to me that all objections would be overcome by a combination of the two systems, and I should propose that the proof pressure should be $1\frac{1}{4}$ times the working pressure + one atmosphere. If this was adopted, we should have a

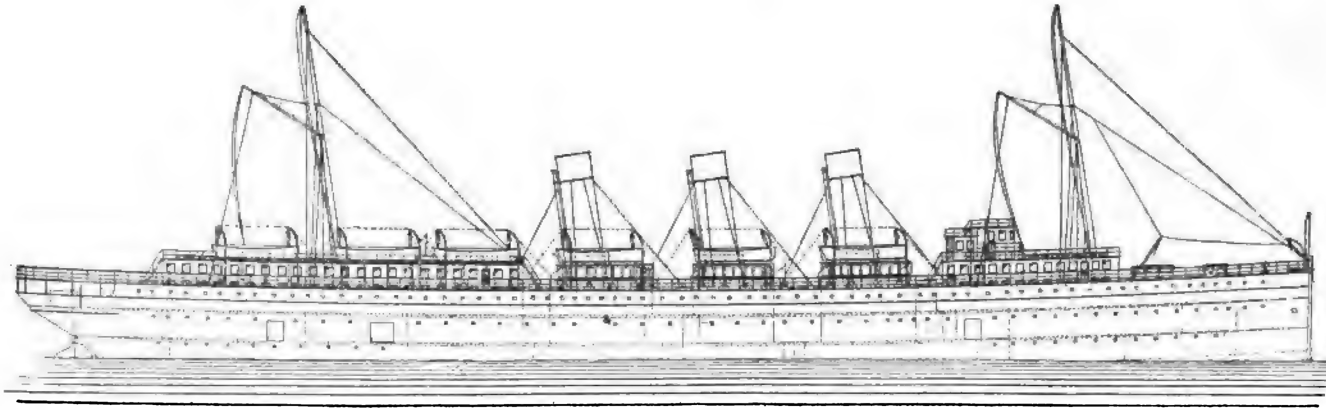
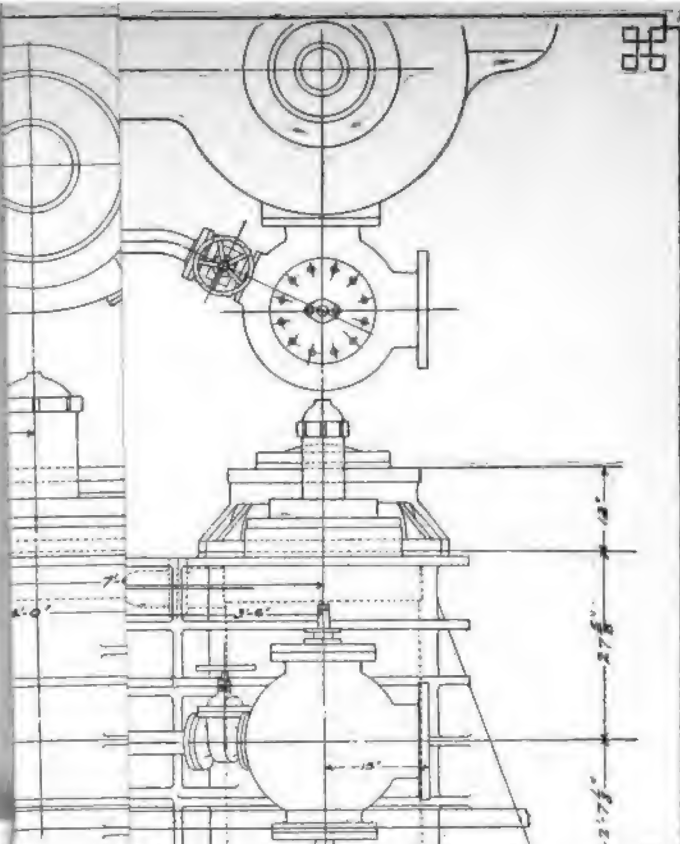


Fig. 36.



full value for the rivet section in the calculation when the same is in double shear; the latter, viz., the German Lloyd's, appears to do so at first sight, but it will be seen that the handicapping is done in the increased factor of safety. Why the full value should not be given when the riveting is done by a machine, if it is allowed for rivets in single shear, I fail to see; but we should be slow to find fault with this provision, as, if it errs at all, it is on the side of giving increased strength and tightness where much required.

It may also be noticed that in the Board of Trade rules, when additions are made to the factor of safety for the shell, the rivets themselves are not affected; they remain the same as if the shell was made with the factor 4.5. If the addition is one put on because of the nature of the holes, should it not affect the rivets also? and in this respect should we not fall in with the provisions of the Bureau Veritas rules? Referring again to the Board of Trade additions, it may well be asked why in all cases they should be cumulative. For instance, suppose the method of construction is such as to cause an addition to F for the circumferential seams as well as for the longitudinal, would it not be more reasonable to take whichever was greatest instead of the sum?

The minimum thickness for butt-straps prescribed in the Board of Trade rules is rather less than would be dictated by experience for most riveting, and the ratio established by the German Lloyd's is more satisfactory. In any case, it is difficult to agree with the hard-and-fast limit as regards maximum pitch, adopted by both these bodies. Indeed it is abundantly evident that we still require a satisfactory expression for the extreme relation between the pitch and thickness of plate, or between the latter and the distance between side of rivet and side of rivet.

Referring to the factor of safety of 4.4 established by the Bureau Veritas; seeing that there are no additions as in Board of Trade rules; and on the supposition that the calculated stress actually comes on the joint during the hydraulic test; I should say that it was too low, especially for lap-joints or lap and butt joints with thick plates. I give in the Appendix some notes on the noticeable movement of joints, as recorded from certain experiments, the source of which I cannot remember. The results are rather startling, and often

inconsistent; but we may be quite sure that similar inconsistencies exist in practice.

Material for Boilers.—Steel being the metal now almost exclusively used for boilers, let us confine ourselves to it; otherwise our review would be extended to an inconvenient length, and might be wanting in interest and value from its very bulk.

For boiler construction we require a material as strong as we can reasonably get it, provided it has certain other very necessary qualifications, some of which are, doubtless, in the opinion of most, of much more consequence than great strength.

To save confusion, I shall take the material for each part of a boiler, as we go on, under the heading of that part.

Referring to "elongation," it will be seen that in any suggestions made on the subject of material I have used 8″ as the standard of length. The reason of this is, not that I approve of that standard where the inch is the unit of measure, but because it is the length universally used on the European continent, as well as largely in Britain, and is the one to which I have been most accustomed.

Material for Cylindrical Shells subject to Internal Pressure.—The qualities of material prescribed are as follows:

Board of Trade.—Tensile strength to lie between the limits of 27 and 32 tons. In the normal condition, elongation not less than 18% in 10″, but should be about 25%; if annealed, not less than 20%. Strips 2″ wide should stand bending until the sides are parallel at a distance from each other of not more than three times the plate's thickness.

Lloyd's.—Tensile strength between the limits of 26 and 30 tons per square inch. Elongation not less than 20% in 8″. Test strips heated to a low cherry-red and plunged into water at 82° F. must stand bending to a curve, the inner radius of which is not greater than 1½ times the plate's thickness.

U. S. Statutes.—Plates of ½″ thick and under shall show a contraction of area of not less than 50%; when over ½″ and up to ¾″, not less than 45%; when over ¾″, not less than 40%.

Bureau Veritas.—The tensile strength not to exceed 30½ tons per square inch, and the elongation, respectively, not to be less than as follows: if 30 tons, 20%; if 29 tons, 21%; if 28 tons, 22½%; if 27 tons, 23%; if 26 tons, 24%; if 25 tons, 25½%; if 24 tons, 27%; if 23 tons, 29%; if 22 tons, 31%. Strips 1½″ to 2″

wide, after being heated to a dull red and plunged into water at 82% F., must stand bending over a radius equal to 1½ times the plate's thickness.

German Lloyd's.—The higher tensile limit appears to be 30½ tons, although it is not distinctly stated; the elongations, respectively, not to be less than as follows: 30½ tons, 20%; 30 tons, 20%; 29 tons, 20½%; 28½ tons, 21%; 28 tons, 21½%; 27½ tons, 22%; 26½ tons, 22½%; 26 tons, 23%; 25½ tons, 23½%; 25 tons, 24%; 24 tons, 24½%; 23½ tons, 25%; 23 tons, 25½%; 22½ tons, 26%. Strips 1″ wide heated to redness ten minutes and plunged when in that condition into water at 82° F., to stand bending over a radius equal to twice the plate's thickness.

Let us glance at the requirements. The shell plates have to stand bending cold without injury; corners have to be thinned down; seams have to be closed, and should be capable of standing considerable abuse in such an operation; the seams have also to be riveted without any danger of the holes cracking out during the operation; and altogether the material should be of such a nature as to lend itself kindly to all these operations without causing anxiety during construction or during the life of the boiler when in service. In the case of mild and ductile material, the thinning of corners appears to do no harm provided the parts actually hammered are heated to redness afterward, local heating itself not being detrimental when confined to a corner. Referring to local heating: when the plates are thick they should be able to stand being locally heated without risk, as at times they cannot be drawn up owing to their stiffness without it; the necessity for this may be getting less every year, but until the joints are machined as in engine work, it is probable this difficulty will not be completely overcome. If all boilers were designed, as they should be, so that all the seams of the shell could be closed and riveted by hydraulic or other machinery, the difficulty of closing would be overcome, and perhaps local heating need never be resorted to.

It should be remembered that a mild material is less subject to the sudden and mysterious flaws which occasionally develop in steel plates. It should also be remembered that although a chain may be reckoned for strength by its weakest link, the weakest part of a boiler shell of ductile material cannot be compared to the proverbial link: a weak part being

lost in the strength of the whole, some parts would stretch and allow the great whole to come into play.

Of necessity the rivets must be of ductile material; if so, it may be asked, What is the necessity of having of harder quality the material in which the holes are, as the pressure on the hole and rivet are the same; and if the stress is limited so as not to injure the rivet, it will not injure the plate? The actual strength seems to me of little consequence within considerable limits, and the compensating advantages may far outweigh any deficiency in strength; in fact, I believe all will admit that a lower nominal factor of safety might be accepted with a ductile material than with a brittle one.

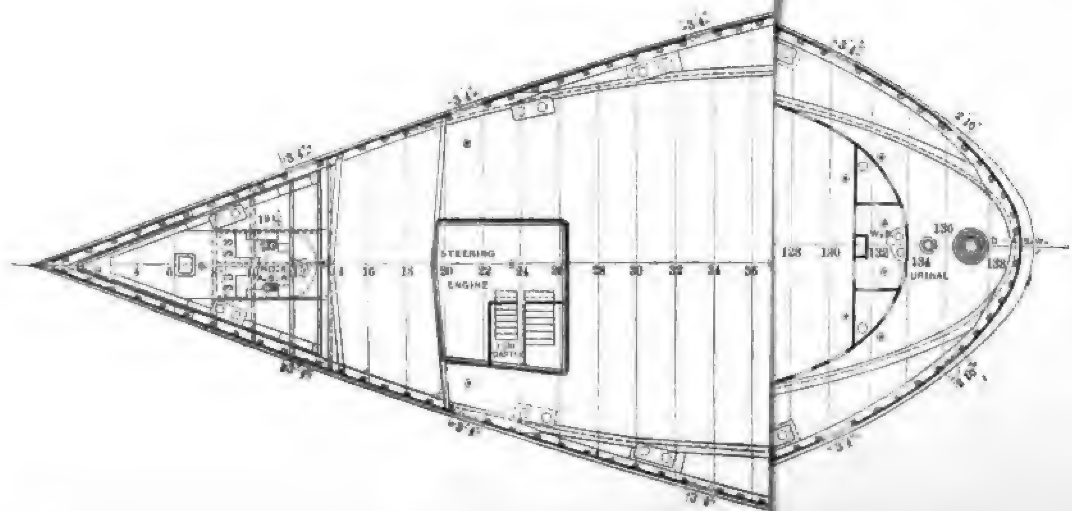
The Board of Trade rules seem to indicate a steel of too high a quality when a lower and more ductile one can be got; the lower tensile limit should be reduced, and the bending test might, I think with advantage, be made after tempering, and made to a smaller radius. Lloyd's rule for quality seems more satisfactory, but the temper test is not severe. The United States Statutes, although wisely not fixing a higher limit for tension, are not sufficiently stringent to insure an entirely satisfactory material. The Bureau Veritas and the German Lloyd's rules appear the most satisfactory, except that a temptation exists to use the higher qualities, as an advantage is given to the same, as will be seen in the shell-plate formulæ which follow.

I would suggest a material which would meet the following: 25 tons lower limit in tension; 25% in 8″ minimum elongation; radius for bending test after tempering = the plate's thickness.

Shell-plate Formulæ.—*Board of Trade.*—Where

D = diameter of boiler in inches;
P = working pressure in lbs. per square inch;
t = thickness in inches;
B = percentage of strength of joint compared to solid plate, of plate or rivets, whichever least;
T = tensile strength allowed for the material in lbs. per square inch;
F = a factor of safety, being 4.5, with certain additions depending on method of construction.

$$P = \frac{T \times B \times t \times 2}{D \times F \times 100}$$



TANCHIONS 5 X 7 BELOW RAIL
" 4 X 6 ABOVE "
GHTS MARKED THUS *

Bureau Veritas.—The factor of safety is taken at 4.4, and T is the lowest or lowest assumed tensile strength; also, .04″ is to be deducted for corrosion; then

$$P = \frac{T \times B \times (t - .04)^2}{D \times 4.4 \times 100},$$

where B is the percentage of the plate section at the joint. Of course P will depend also on the rivet section, in which case the same factor 4.4 is used as a divisor for the shearing strength as already mentioned under Riveting.

German Lloyd's.—

$$P = \frac{t \times 2 \times B \times T}{D \times F \times 100},$$

where B is the percentage of plate section at the joint and F a variable factor of safety depending on the thickness of the plating, taking the following values: for plates $\frac{13}{32}$ and not above $\frac{19}{32}$, $F = 5$; $\frac{19}{32}$ and not above $\frac{25}{32}$, $F = 4.85$; $\frac{25}{32}$ and not above $\frac{31}{32}$, $F = 4.8$; $\frac{31}{32}$ and not above $\frac{37}{32}$, $F = 4.75$; $\frac{37}{32}$ and not above $\frac{43}{32}$, $F = 4.7$; $\frac{43}{32}$ and above, $F = 4.65$.

Before analyzing the rules with a view to their consideration with reference to the purpose for which they were intended, let us first consider whether we know at all or not, how to calculate the theoretical resistance to bursting of a cylindrical boiler shell.

Previous to commencing this review, I had myself little doubt on the subject, viewing it in a very everyday light, namely: First, as a ring loaded with an even pressure inside all round, the total load per unit of length tending to tear it asunder being simply the diameter × the pressure per square unit of surface; this I assumed, I dare say, in common with most engineers, to give a direct tensional stress on the ring. Secondly, I viewed it as a barrel, with an infinite number of straight staves bound to the ends, viz., like a barrel hooped only at the ends, one stave being otherwise quite independent of another. A stave then becomes a beam loaded evenly; the other conditions being that the ends are either fixed and unable to approach each other, or that the ends are free to move. Probably owing to the end plates not being perfectly rigid, a

mean of the two conditions just mentioned might be near the truth.

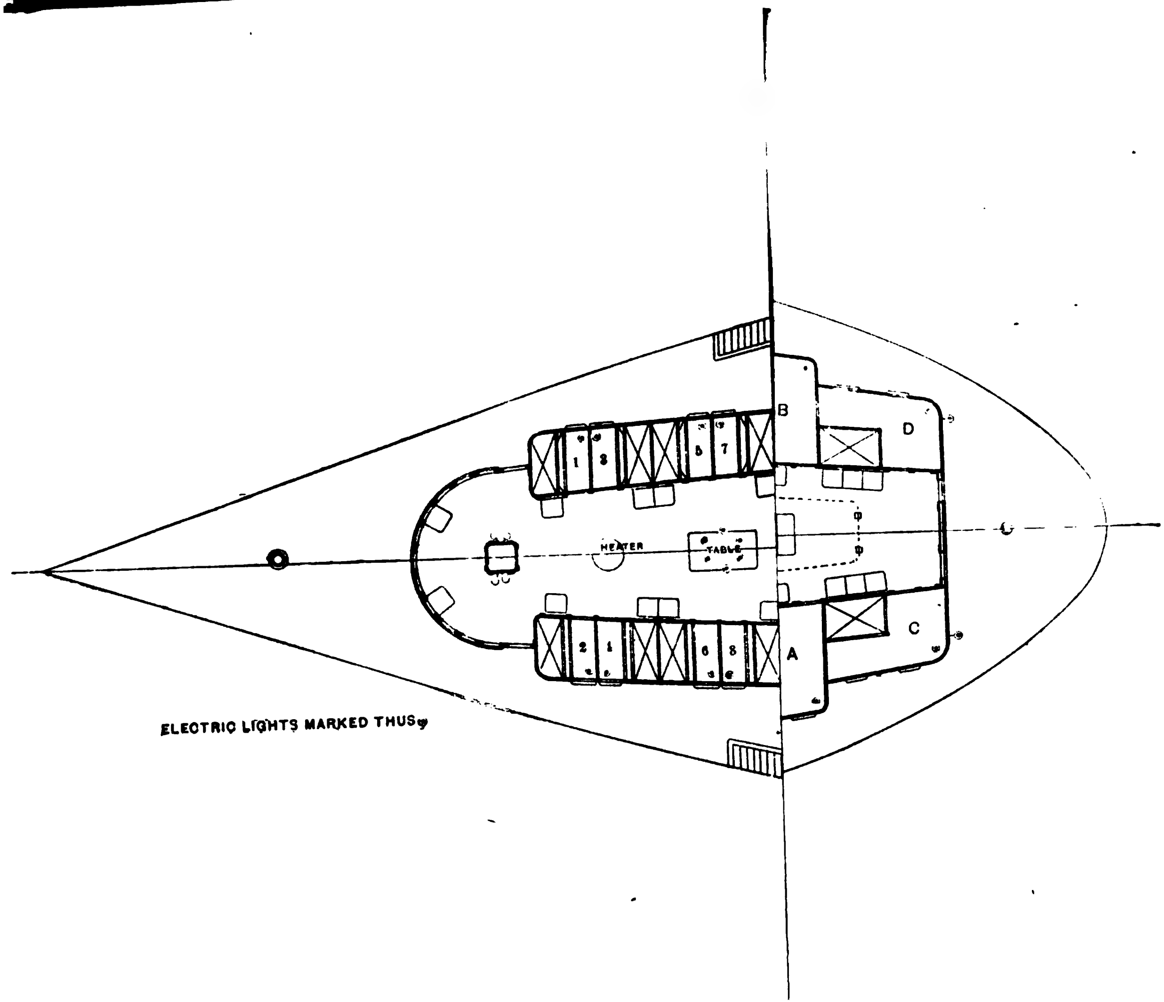
If the ends are loose, the bending moment in inch pounds would be, $\frac{\text{load} \times \text{length of boiler in inches}}{8}$; and if fixed, $\frac{\text{load} \times \text{length in inches}}{24}$. Taking a stave 1″ wide, the moment of resistance would be, in inch-pounds, = (thickness of plate in inches)$^2 \times 1 \times$ tensile strength per square inch $\times$ .2886.

Assuming a mean value for the bending moment, it will be found on taking an example that the value of such a beam would be very little; in fact, a stave of a boiler 10 feet long with a shell plate 1″ thick is only good for $\frac{3}{8}$ lb. on the square inch if the tensile strength of the material is taken at 60,000 lbs. From reasoning such as what has gone before, I was in the habit of discarding the barrel view of the subject, and confining myself only to the ring until the present time.

Before proceeding to a third way of looking at the matter, I may mention that, a few years ago, Mr. Spence of Newcastle-on-Tyne had the audacity to suggest, in a paper he read before the North-East Coast Institution of Engineers and Shipbuilders, that the length of the boiler should be made a factor in calculating the resistance of the cylindrical shell to bursting. I have not followed Mr. Spence's arguments, but read some of the discussions with considerable interest, and noticed that he got very little support even from his fellow-engineers; further, a mathematician writing from Oxford University, after a most elaborate investigation, went so far as to say that the presence of the ends in a boiler assisted only to an infinitesimal degree when the length was within the limits which usually obtain in practice.

Let us now look upon the problem in a broad way, if possible free from preconceived ideas, giving due consideration to phenomena which are visible to our eyes nearly every day. If it is thought that such phenomena have a bearing on the subject, it is right that they should be investigated; if not, no harm is done in bringing them into prominence.

Many may have noticed that when a glass tube is heated in the middle to a full red heat, and the ends drawn away from each other, the tube contracts in diameter at the part where it is sufficiently hot to yield. That this phenomenon is


B
D
1
3
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7
HEATER
TABLE
2
4
6
8
A
C
ELECTRIC LIGHTS MARKED THUS

diameter at the middle from internal pressure more than at the ends, as it naturally must (the diameter at the ends from the very nature of the circumstances being practically constant), the said stretching and increase of diameter at middle tends to draw the ends together as already described. This action is resisted by the steam-pressure on the ends and by the stays; it therefore follows that some portion of the load at the centre is transmitted to the ends in lines which make it apparently evident that the tensional stress, acting in the circumferential direction on a ring at the centre, cannot be that due to the whole internal pressure on its surface.

In order to add point to the argument, let us lastly put the matter in this way. Supposing we had a boiler the shell of which had an exceedingly wide lap-joint longitudinally, with the rivets left out; and supposing some elastic cement was placed over the joint to take the place of calking for moderate pressures: would or would not the boiler burst when the pressure was raised above zero? All our rules say yes; but in spite of this, is it not evident that a considerable pressure would be reached before the elastic limit at the weak part was reached. It must be remembered that the percentage of strength at the joint is 0 compared with the solid plate.

Are we not finally led to the conclusion that until the ratio of length to diameter becomes very considerable, the ends play an important part in determining the lines of force in a cylindrical boiler shell subject to internal pressure, and that they therefore play a very important part in its ultimate resistance?

The only experiments of which I can find accounts that bear at all on the subject directly are the following:

Mr. Scott's Experiment.—A boiler was constructed by Mr. Scott of Greenock, of new material, 7′ $8\frac{3}{16}$″ mean diameter by 11 ft. long, without internal parts, but the ends were stayed with longitudinal stays in a similar manner to what is usual in practice. As far as scantling was concerned, the shell was identical with that of an actual boiler for the British Admiralty, intended to work at 145 lbs. per square inch. The result of the hydraulic trial to burst the shell was briefly this: At 620 lbs. per square inch the trial had to be abandoned, as leakage overcame the water supply from the pumps; but practically

the shell was considered uninjured, the said leakage being confined to a few places.

The tensile resistance of the material was known, and the calculated percentage of strength at joint was 83. Yet what do we find?—that the leakage only overcame the pumps when the pressure arrived at 93% of the actual calculated bursting pressure, and that the boiler ought to have been destroyed by the calculated limit of elasticity being overstepped long before serious leaking occurred.

Mr. Spence's Experiments.—

1st	model	boiler	shell	26″	diam.	× $44\frac{5}{8}$″	long,	with	ends	stayed.
2d	"	"	"	26″	"	× $25\frac{7}{8}$″	"	"	"	"
3d	"	"	"	26″	"	× 13″	"	"	"	"

The shell-plating was in all cases $\frac{3}{16}$″ thick, single-riveted in longitudinal seam, 55% of material left between the holes.

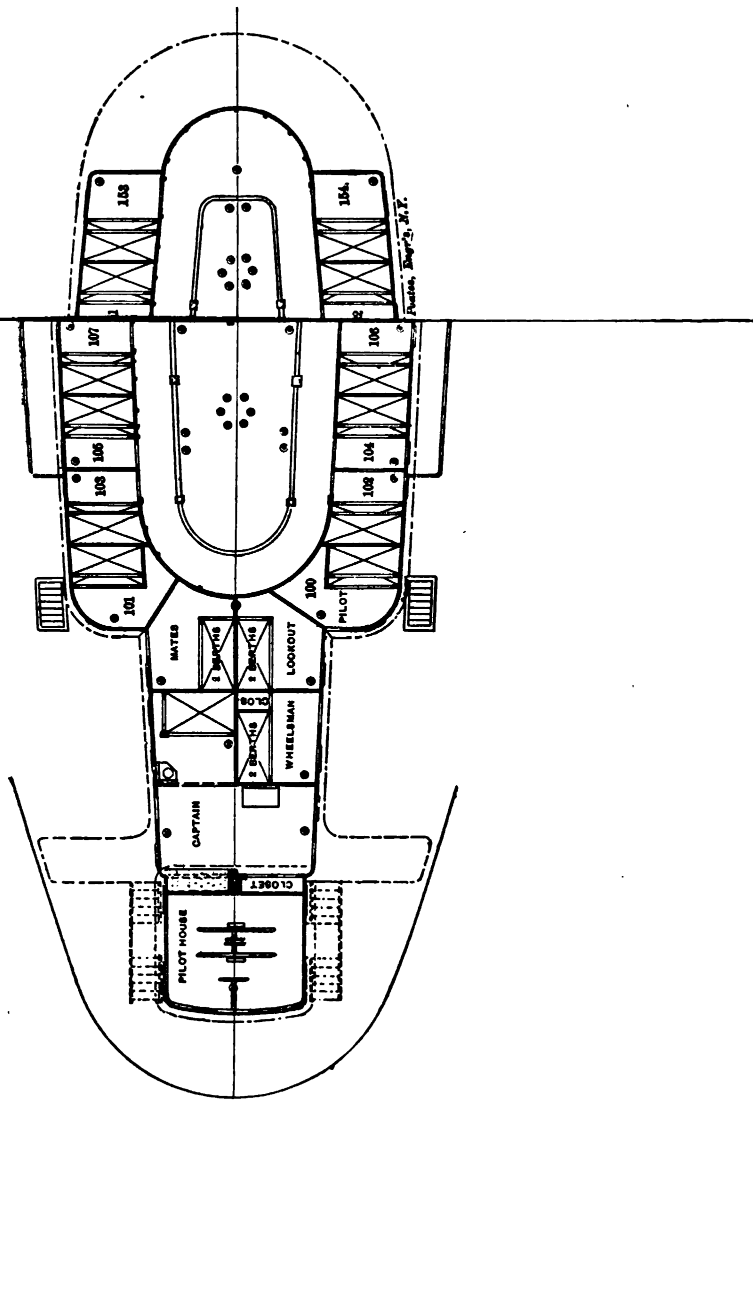
Results: 1st, leaking overcame the pumps at 720 lbs. per square inch; 2d, leaking overcame the pumps at 680 lbs. per square inch; 3d, joint gave way, burst, at 800 lbs. per square inch.

The joints of the first two appeared to have suffered little more than the solid plate, but no addition of strength could have been obtained from friction, as a penknife could be shoved into the joints at the latter stages of the trials.

The calculated bursting pressure was in all cases 506 lbs. per square inch, and the calculated elastic limit 328 lbs.

Manchester Steam-users' Association.—A new Lancashire boiler, 7 ft. diameter by 21 ft. long, with iron plates $\frac{7}{16}$″ thick, punched holes, double-riveting, rivets $\frac{25}{32}$″ diameter, $2\frac{3}{8}$″ pitch, joint 68% compared to solid plate. The boiler burst by the rupture of a longitudinal seam, at 300 lbs. per square inch, which was practically the calculated strength. Considering the damage done by punching, it seems strange it did not give way earlier.

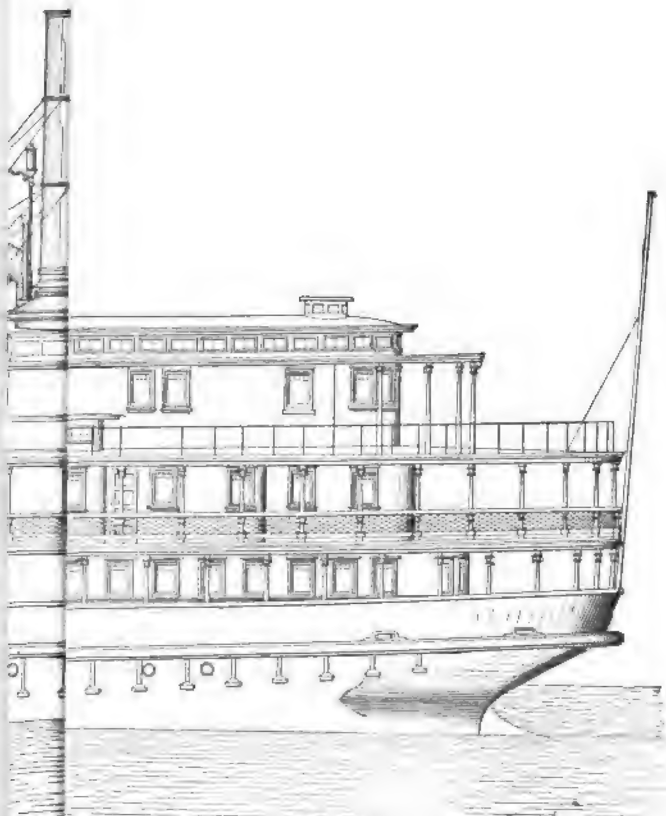
Shell-plate Formulæ.—Now let us proceed to analyze the existing rules for cylindrical shells subject to internal pressure. The principal feature of the Board of Trade rule is that the factor of safety is made variable, depending upon the method adopted in the construction of the boiler. If we believe that the longitudinal joint is not subject to the stress which is usually supposed to come upon it. yet we must admit that the


153
154
107
106
105
104
103
102
101
100
PILOT
MATES
2 BERTHS
2 BERTHS
LOOKOUT
CLOS
WHEELSMAN
2 BERTHS
CAPTAIN
CLOSET
PILOT HOUSE

tion, no more efficient or satisfactory enactment seems probable on the part of the government until the creation of a Department of Commerce to deal with the numerous commercial matters now administered by the Secretary of the Treasury, who can have but little disposition and less time to deal with them.

To correct some of the shortcomings of the present Steamboat Laws, the American delegates to the International Marine Conference found it necessary to recommend that the existing inspection rules should be revised by *experts*, and that new rules be formulated if necessary. The Secretary of the Treasury, recognizing the force of such a recommendation emanating from such a source, convened a board of five experts, to whom he referred the matter of such a revision. It is a strong official commentary on the inefficiency of the system of appointing supervising inspectors that none of the members of this board were selected from their ranks. The gentlemen designated as members of the board studiously applied themselves to the task assigned, and placed themselves in communication with most of the leading marine organizations of the country, and finally submitted to the Secretary of the Treasury the result of their labors, in the form of a bill proposed for enactment by Congress. This bill was introduced by Senator Frye of Maine, the Chairman of the Senate Committee on Commerce, in January, 1892, and entitled "A Bill to amend certain sections of Title Fifty-two of the Revised Statutes of the United States, and to carry into effect certain recommendations of the United States delegates to the International Marine Conference." The failure of this bill to become a law seems not to be an unmixed evil, for some of its provisions are clearly unwise, owing probably to the fact that the experts felt called upon to carry out the recommendations of the Conference, some of which had been made in a too general form.

The American people have seldom failed to ultimately solve problems to which they have resolutely addressed themselves, and the writer's wish may be father to his thought that the next great national undertaking which they will solve will be the rehabilitating of American commerce on the sea, by which American iron and steel manufacturers will find an increased demand for their productions, and at the same time,



Bradley & [illegible] Engr's N.Y.

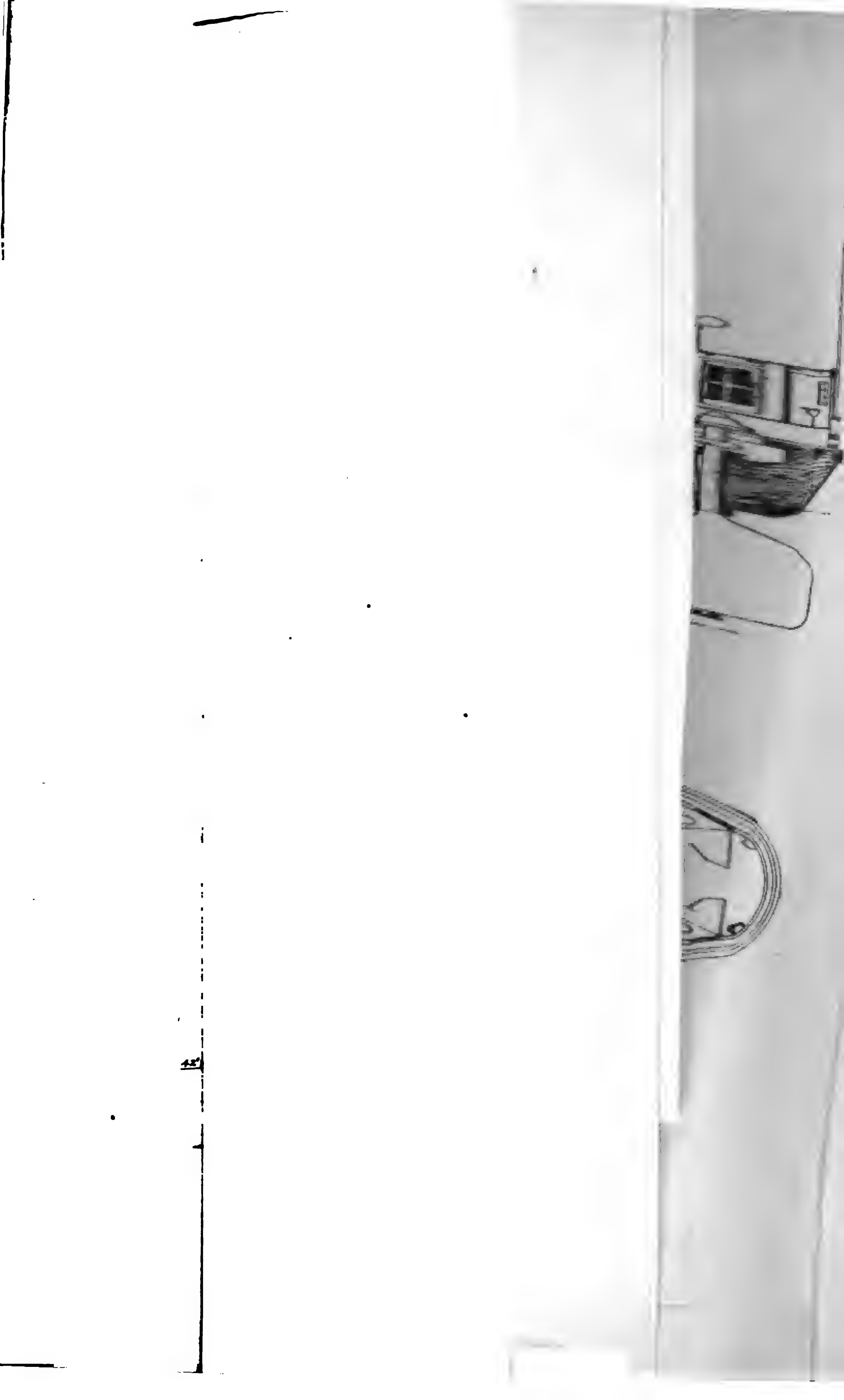
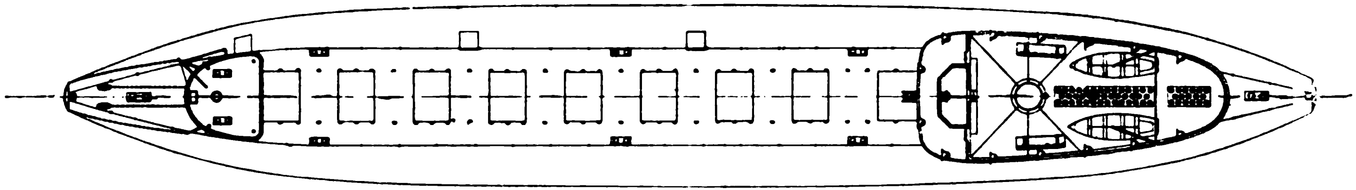
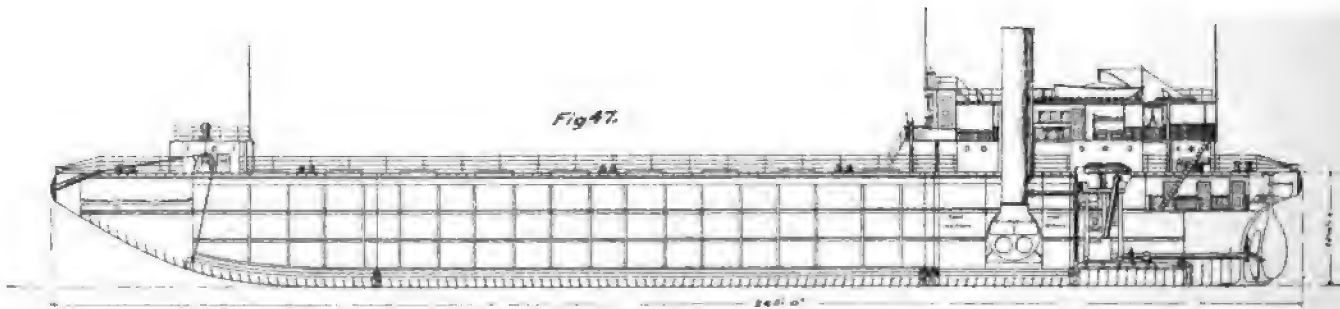

42'

Fig.46.



— Plan —

Fig.47.



— Longitudinal Section —

ordinary marine boiler flame-boxes bulged into the flame-box between the stays, and the same impression was left.

Let us think for a moment what this bulging means. It means that in addition to the bulging, which in itself might not be objectionable, the stay-hole is being enlarged, and that, if carried to extremes in the case of riveted heads, the threads of the hole will eventually be clear of the threads of the stay end; the riveted head is then left to take the load, and at last either the plate slips over the head, or the head itself, which is riveted cold, comes off. In the case of nuts, the same action takes place, but the final result is of course different; in both cases the threads are practically uninjured.

In the case of screwed stays, therefore, whether fitted with nuts or not, we must take care that no such action takes place as to cause permanent enlargement of the hole.

Some years ago, some admirable experiments were carried out by the British Board of Trade on flat surfaces stayed in various ways. The results appeared in a report published in 1881. From these experiments, it would appear that permanent set between the stays usually developed considerably before (but sometimes not much) definite signs showed that something was going wrong at the stay ends or holes. The superiority of nutted stays was well shown also, not as regards permanent set between the stays, but as regards the final giving way.

From the study of these experiments, I should say that we may assume that permanent injury may begin at the holes when permanent set commences between the stays, and that the hydraulic test should be well within the limit.

It is also evident that a ductile material is in a worse condition to resist enlargement of the holes than a material of the reverse quality; but there being other very important reasons why the material of flame-boxes should be ductile, it makes it all the more necessary, in their case at any rate, that we should not go to extremes in the pitch of the stays. We must also remember that the plates are hot, and how hot we cannot tell; this will depend, not only on their thickness, but also on the amount and quality of the foreign matter on the water side.

All things considered, it is evident that, in the case of flat surfaces exposed to fire, a liberal allowance should be made

in the factor of safety, and it scarcely becomes a question of hydraulic test and permanent set. These considerations might, however, enter into account for plates not so situated.

Certain other experiments, besides those alluded to, were also carried out by the Board of Trade, which showed that the resistance to bulging does not vary as the square of the plate's thickness. There seems also good reason to believe that it is not inversely as the square of the greatest pitch. Be this as it may, as it is the enlargement at the holes we have chiefly to deal with, it might naturally be supposed that the true investigation would be of a very complex character. Bearing in mind that mathematicians have signally failed to give us true theoretical foundations for calculating the resistance of bodies subject to the simplest forms of stresses, we therefore cannot expect much from their assistance in the matter of flat plates.

Take, for example, in order that my meaning may not be misunderstood, the case of bodies subject to what is called simple tension. Suppose two bars, both of the same material, one plain and the other screwed, say Whitworth thread: is there any mathematician alive who could tell us the theoretical relative strengths per unit of cross-sectional area? Further, suppose one hollow and the other solid; again, suppose a flat bar solid and another with a hole drilled in it, reducing the section: the same question in all cases—Where is the mathematician to solve the problem? If we are in such an unfortunate position in the case of tensile stresses, what can we expect where the solving must be a much more complex operation? For my part, I am still open to conviction, even as to the strength of a beam varying directly as its breadth, although this is laid down as a definite axiom in all text-books.

The Board of Trade rules for flat surfaces, being based on actual experiment, are especially worthy of respect; sound judgment appears also to have been used in framing them. Mr. Traill, however, makes this very pertinent remark: "that a simple rule (the only kind admissible) such as the Board adopted must necessarily be incorrect outside a very limited range." As far as I can gather, they aim at a factor of about $5\frac{1}{2}$ between permanent set and working pressure. For plates exposed to fire and subject to such uncertain conditions as already alluded to, perhaps we should be justified in adhering

to the rules as they are; in the case of plates not subject to such action it appears to me that the constants might be modified. Might we not approach nearly to the permanent set point with the hydraulic test,—I mean within reasonable limits,—as is done in testing a chain at the proof load?

I may mention, before leaving the Board of Trade rules, that some limit might with advantage be established for the ratio of the sides of the rectangle when the form of square is departed from.

Lloyd's rule assumes the strength to vary as the square of thickness, which, as before stated, experiment has not corroborated; otherwise they are pretty much on the lines of the Board of Trade rules as far as scope goes. The ratio of the constants for similar conditions are different, however. Take, for instance, riveted heads and nutted stays: for plates under $\frac{7}{16}''$ thick, the ratio is $\frac{90}{100}$, viz., .9; whereas in the Board's rule it is .66; and it may be added that the experiments already referred to are much more in accordance with the latter ratio. The jumping of the constants to new values is also objectionable in the case of Lloyd's rules.

The U. S. Statute rules also assume the resistance to vary as the square of plate's thickness. In other respects they are somewhat similar to Lloyd's, but not so elaborate in the matter of constants.

The Bureau Veritas rule brings in the tensile strength as a factor. As the permanent set (and the consequent injury) depends to a great extent on the strength of the material, it seems permissible to make it a factor, provided the elastic limit varied directly with it. For plates subject to the action of fire, this seems a dangerous basis to build upon, as it would offer a temptation to designers to use a harder material than their unbiased judgment would otherwise prescribe.

In other respects, also, the formula differs altogether from those gone before; the $(a^2 + b^2)$ seems an improvement on the p^2 of Lloyd's and the U. S. Statutes, but how far this factor falls in with actual truth it is difficult to say. The deduction of $\frac{1}{16}$ for corrosion seems quite out of place, there being often absolutely none; and further, the amount could, under no circumstances, be estimated.

In the German Lloyd's rule, we have P varying as t^2, and we have p^2 as a factor instead of the surface; otherwise it is

very similar to that of the Board of Trade, viz., in the matter of constants; it is, as it were, the Board's rule combined with Lloyd's.

Material for Furnaces.—The qualities of material prescribed are as follows:

Board of Trade.—The tensile strength to range between 26 and 30 tons, with an elongation of not less than 20% in 10″. Strips 2″ wide should stand bending until the sides are parallel at a distance apart of three times the thickness of the plate without showing sign of fracture, after being heated to usual tempering heat and quenched in water.

Lloyd's.—Steel of 26 to 30 tons tensile strength, with an elongation of not less than 20% in 8″, is allowed the highest pressure for a given thickness. A milder quality is passed, although at a disadvantage in the case of the Fox furnace.

U. S. Statutes.—No special provision appears to be made, and therefore it is to be presumed that the steel must be of the usual boiler quality, namely, to have a reduction of area during tensile test of not less than 50% if ½″ thick and under, 45% if over ½″ and up to ¾″, and 40% if over ¾″.

Bureau Veritas.—Steel of 30½ tons tensile strength and 20% elongation can be used for all parts of boilers; but it is strongly recommended not to use for furnaces steel above 28 tons tensile strength with 22% elongation, and for corrugated furnaces 25½ ton steel, with 25% elongation in 8″. Strips 1½″ to 2″ wide, after being heated and plunged at the usual tempering heat into water at 82° F., must stand bending double over a radius equal to 1½ times the plate's thickness.

German Lloyd's.—As far as I can understand the rules, the range of qualities given for the cylindrical shell plates is allowed also for furnaces, provided the corresponding elongations are maintained; but it is strongly recommended to use a steel of not more than 26½ tons tensile strength, with an elongation not less than 22½% in 8″. Strips 1″ wide, after being heated to the tempering heat for ten minutes and plunged in water at 28° Celsius, must stand bending up to an angle of 180°, the radius being equal to the thickness of the plate.

Considering the subject of material for furnaces, it should be borne in mind that besides the abuse to which the material is subject in common with shell plates and flanged

plates, it is also subjected to very extreme changes of temperature. Not only this, but one side of the plate may be very much hotter than the other,—how much we cannot tell, as this depends not only upon the thickness of the plate, but also on the condition of the water side, which may have foreign matter deposited upon it. Referring to the thickness, certain experiments carried out by the late Dr. Kirk are very instructive; copies of his letters which appeared in *Engineering* on this subject will be found in the Appendix. I only allude to the thickness just now, because the stresses set up on account of the difference of temperature should have some bearing on the quality used.

Experiments as to the behavior of mild steels at various temperatures under tensile stress do not help us much in choosing. Broadly speaking, they seem to show that as the temperature rises, the tensile strength falls less slowly for very mild steel than for the higher qualities; but at a temperature of 600° or 700° F. the higher has yet a slightly higher elastic limit, and it is not until about 1200° is reached that we have them equal. Also, without going into refinement, the tensile strength of both qualities increases up to 600° F., then drops gradually; but the difference between the two remains for all practical purposes the same throughout.

We are therefore thrown back on practical considerations to guide us. We know that the mild qualities lend themselves better to the usage of the boiler-shop, and we can infer that a very mild quality with great ductility will stand the stresses brought on by molecular movement while heating and cooling better than a high quality. Direct proof is difficult to be had, but certain experiments made by Mr. Blechynden of Barrow seem to confirm this; these experiments were made for another purpose, on iron and steel tubes in a tube plate subjected to the same temperature. To me it seems that the results require corroboration; but, if true, we must infer that the nearer we approach to pure iron the more suitable will the material be for furnaces and other parts subjected to an intense heat. In the Appendix will be found accounts of the experiments to which I allude, both here and in the last paragraph.

Taking all the circumstances into consideration,—the liability to cracking at the flanging, especially at the turn-up to

the flame-box; the possible cracking at rivet-holes, and the evil effects of the stresses from changes of temperature, aggravated, as may be the case, by the presence of scale; and also the fact that often a furnace mouth may require considerable "drawing up" to the furnace mouth plate, involving at times this local heating; I think all will agree that the higher qualities of steel should in some way be handicapped —say by granting a lower factor of safety to steel of extreme ductility than to the higher qualities.

All the rules seem to err in permitting the harder qualities to be used, and Lloyd's rules even give an advantage to the higher qualities in the case of Fox corrugations—one of the furnaces of all others where a mild quality is advisable. Broadly, I should say that, in a plain furnace, ductility is not so important; but, in the case of Adamson rings or patent furnaces, it is most advisable.

The recommendation of the Bureau Veritas, not to use steel above 25½ tons tensile strength, is certainly advice which should be followed. I should, however, prefer the following rule for quality: the lower limit of tensile strength to be 24 tons, minimum elongation 26% in 8″; and that, after being heated to the usual tempering heat and plunged into water at 82° F., it be essential that the sample stand bending until the sides are closed up together, the higher limit for tensile strength being whatever it comes. The lower limit I have suggested, it will be noticed, is what might be expected from Lowmoor iron.

Furnace Formulas.—BOARD OF TRADE.—*Long Furnaces.*—Where

P = working pressure in pounds per square inch;
t = thickness in inches;
D = outside diameter in inches;
L = length of furnace in feet up to 10 ft.;
C = a constant as per following table;

$$P = \frac{C \times t^2}{(L+1) \times D},$$ but not where L is shorter than $(11.5t - 1)$, at which length the rule for short furnaces comes into play.

Drilled holes.
$C = 99000$ for welded or butt-jointed with single straps, double-riveted;
$C = 88000$ for butts with single straps, single-riveted;
$C = 99000$ " " " double " " "

Punched holes.
- $C = 93500$ for butts with single straps, double-riveted;
- $C = 82500$ " " " " " single- "
- $C = 93500$ " " " double " " "

Drilled holes.
- $C = 88000$ for laps double-riveted and bevelled;
- $C = 82500$ " " " " not "
- $C = 77000$ " " single- " and "
- $C = 71500$ " " " " not "

Punched holes.
- $C = 82500$ for laps double-riveted and bevelled;
- $C = 77000$ " " " " not "
- $C = 71500$ " " single- " and "
- $C = 66000$ " " " " not "

N. B.—One of the conditions of best workmanship is, that the joints are either double riveted with single butt-straps, or single-riveted with double butt-straps, and all holes drilled in place after bending.

N. B.—In the case of the fire-boxes of donkey or similar boilers, 10% should be deducted from the constants; and when a superheater is constructed with a tube subject to external pressure, the above constants to be reduced in the ratio 30/47.

Short Furnaces, Plain and Patent.—Same notation; but let it be noted that $D =$ outside diameter of plain furnaces, outside over plain part for ribbed, and *least* outside for Fox & Morison; also, that L is length from centre to centre of Adamson joints.

Then

$$P = \frac{C \times t}{D} \text{ for all the patent furnaces named;}$$

$$P = \frac{C \times t}{3 \times D}\left(5 - \frac{L \times 12}{67.5 \times t}\right) \text{ when with Adamson rings.}$$

Furnace Rules.

$C = 8800$ for plain furnaces;

$C = 14000$ for Fox; minimum thickness $\frac{5}{16}''$, greatest $\frac{5}{8}''$; plain part not to exceed $6''$ in length;

$C = 13500$ for Morison; minimum thickness $\frac{5}{16}''$, greatest $\frac{5}{8}''$; plain part not to exceed $6''$ in length;

$C = 14000$ for Purves-Brown; limits of thickness $\frac{7}{16}''$ and $\frac{5}{8}''$, plain part 9″ in length;

$C = 8800$ for Adamson rings; radius of flange next fire $1\frac{1}{2}''$.

LLOYDS.—*Long Furnaces.*—$P = \dfrac{89600 \times t^2}{L \times D}$, but not to be used where L is less than $10.11t$.

Short Furnaces, Plain and Patent.—Same notation, with addition that $\tau =$ thickness in sixteenths of inch and $D =$ outside diameter in inches for plain, outside over plain part for ribbed, and the *greatest* outside diameter over corrugations for Fox and Morrison furnaces.

$$P = \frac{C \times t}{D} \text{ for plain furnaces. } \left\{ \begin{array}{l} C = 8000 \text{ if } t = \frac{9}{16}'' \text{ and under} \\ C = 8800 \text{ if } t = \text{ over } \frac{9}{16}''; \\ C = 10400 \text{ if one Adamson ring;} \\ C = 11400 \text{ if two Adamson rings.} \end{array} \right.$$

$$P = \frac{C(\tau - 2)}{D} \text{ for patent, etc. } \left\{ \begin{array}{l} C = 1000 \text{ for Adamson rings every } 23''; \\ C = 1000 \text{ for Fox corrugation with steel under 26 tons;} \\ C = 1259 \text{ for Fox corrugation with steel 26 to 30 tons;} \\ C = 1259 \text{ for Morison corrugation with steel 26 to 30 tons;} \\ C = 945 \text{ for Holmes' furnace;} \\ C = 912 \text{ for Farnley spiral.} \end{array} \right.$$

U. S. STATUTES.—*Long Furnaces.*—Same notation.

$$P = \frac{89600 \times t^2}{L \times D}, \text{ but } L \text{ not to exceed 8 ft.}$$

N. B.—If rings of wrought-iron are fitted and riveted on properly around and to the flue in such a manner that the tensile stress on the rivets shall not exceed 6000 lbs. per

square inch, the distance between the rings shall be taken as the length of the flue in the formulæ.

Short Furnaces, Plain and Patent.—P as before, when not 8 ft. long $= \dfrac{89600 \times t^2}{L \times D}$;

$$P = \frac{t \times C}{D} \text{ when } \begin{cases} C = 14000 \text{ for Fox corrugations where } D = \text{mean diameter;} \\ C = 14000 \text{ for Purves-Brown where } D = \text{diameter of flue;} \\ C = 5677 \text{ for plain flues over } 16'' \text{ diameter and less than } 40'', \text{ when not over 3 ft. lengths.} \end{cases}$$

BUREAU VERITAS.—*Long Furnaces.*—Same notation.

$$P = \frac{C \times t^2}{L \times D},$$

where C is 84000 when the furnace is welded or lapped and bevelled, double-riveted; but 72000 when the furnace is not truly circular or simply lapped.

N. B.—In the first case, this rule not to apply when L is less than 10.5 times t, and in the second, when less than $9t$.

Short Furnaces, Plain and Patent.—Same notation as for Board of Trade and Lloyd's.

$$P = \frac{t \times 9000}{D} \text{ for plain furnaces;}$$

$$P = \frac{C \times (\tau - 2)}{D} \text{ where } \begin{cases} C = 1000 \text{ for Fox corrugations;} \\ C = 1160 \text{ for Purves-Brown ribbed;} \\ C = 912 \text{ for Farnley spiral.} \end{cases}$$

GERMAN LLYOD'S.—*Long Furnaces.*—Same notation, except that D = inside diameter in inches.

$$P = \frac{t^2}{.000001 \times D \times L},$$

when L is not less than 119.3 times t.

N. B.—Furnaces are assumed to be either double-riveted with single butt-straps, or single-riveted with double butt-straps. It is also advisable that the joint be not in direct contact with the flame.

Short Furnaces, Plain and Patent.—Same notation, but D = inside diameter for plain furnaces, greatest outside if corrugated, and outside diameter of plain part if ribbed.

$$P = \frac{t \times 8550}{D} \text{ for plain furnaces;}$$

$$P = \frac{(t - .125)16000}{D} \text{ for Fox corrugations;}$$

$$P = \frac{(t - .125)18560}{D} \text{ for ribbed furnaces.}$$

Coming now to examine the rules for long furnaces, we see that the Board of Trade general formula, where the length is a factor, has a very limited range indeed, viz., 10 ft. as the extreme length, and 135 thicknesses, — 12″, as the short limit. The original formula, $P = \frac{C \times t^2}{L \times D}$, is that of Sir W. Fairbairn, and was, I believe, never intended by him to apply to short furnaces. On the very face of it, it is apparent, on the other hand, that if it is true for moderately long furnaces, it cannot be so for very long ones. We are therefore driven to the conclusion that any formula which includes simple L as a factor must be founded on a wrong basis.

With Mr. Traill's form of the formula, namely, substituting $(L + 1)$ for L, the results appear sufficiently satisfactory for practical purposes, and indeed, as far as can be judged, tally with the results obtained from experiment as nearly as could be expected. The experiments to which I refer were six in number, and of great variety of length to diameter; the actual factors of safety ranged from 4.4 to 6.2, the mean being 4.78, or practically 5. It seems to me, therefore, that, within the limits prescribed, the Board of Trade formula may be accepted as suitable for our requirements.

It is scarcely likely that any engineer would desire a less nominal factor of safety than 4¾ or 5 in the cold condition, although it is well known that many work with one much under this. In passing, I may remark that it seems incorrect to fix 10 ft. as the limit of length for the application of the formula irrespective of diameter. Surely the length

should be some factor of the diameter, say 3 diameters, or whatever might be found to correspond with practice.

Lloyd's rule for long furnaces is simply the Fairbairn rule, but there is the restriction to prevent it being applied to very short ones. For an extreme length, no limit appears to be fixed,—it may be presumed because long furnaces do not occur in the mercantile navy of Britain.

The form of the Bureau Veritas rule is also that of Fairbairn's, except that the constant is made to depend on the method of construction, a system evidently copied from the Board of Trade rule. Would it not have been better to copy the Board's rule in full?

The United States Statutes gives Fairbairn's rule pure and simple, except that the extreme limit of length to which it applies is fixed at 8 ft. As far as can be seen, no limit for the shortest length is prescribed, but the rules to me are by no means clear, flues and furnaces being mixed or not well distinguished.

The German Lloyd's give Fairbairn's rule in another form, but the constant is slightly different.

Looking at the subject of long furnaces in a general way, it appears that the factor L is a very unsatisfactory one, and must remain so unless extensive experiments are made. It also appears reasonable that a difference might be made between the constant for a furnace exposed to radiant heat of incandescent fuel, and that for a flue exposed to hot gas or even flame. In practice, however, there would be little inducement for this, except a small saving of weight, because thin plates are most desirable where the heat is strongest,—just where we cannot venture to have them thin,—and where the heat is less intense it is not so important.

Passing on to short furnaces: there seems little doubt that the simple formula, $P = \frac{C \times t}{D}$, which aims at limiting the crushing stress on the material, first adopted by the Board of Trade and afterwards followed by most of the other framers of rules, is a judicious provision; but I am inclined to deny that it is even approximately accurate theoretically, as it appears almost a certainty that the length is a very important factor in a short furnace as well as in those of moderate length, and that an expression of that form cannot give the stress.

I have come to the conclusion that L should appear in some form or another in all furnace formulæ, and would like it to be noted that we have it in the Board of Trade formula for furnaces with Adamson rings. Lloyd's also recognize it to some extent, giving a different value to C under certain circumstances.

In the case of the patent furnaces, all our formulæ are founded on experiment, and take the form $\frac{P \times D}{t}$ = a strength coefficient, so that little can be said. I would have it noted, however, that these experiments have not been carried out in an exhaustive way; the lengths have not been varied. In some patent furnaces I should be inclined to think the length would be a very important factor. Fox's may be an exception, as, according to the experiments of Herr von Knaudt, this furnace is endowed with considerable elastic properties when subject to end thrust or tension.

The collapsing of furnaces probably should be divided into two classes; namely, the collapse due to pure weakness, aggravated as it may be by the heat to which it is subjected, and that due to local heating caused by foreign matter preventing the water from conducting away the heat. With a view to the latter contingency, there is certainly some excuse for the non-recognition of L.

The factor, -2, which appears in the Lloyd's formula for patent furnaces seems objectionable, if it is for corrosion, as it appears to be. It can be said that some furnaces corrode very little or none at all at the parts most liable to collapse. If the -2 is for insuring strength against local heating, it does not appear to be the proper form for such a provision.

Summing up, I think we may conclude that a good formula is still to be sought for plain furnaces, where L shall take its proper place, whether the furnace be long or short. If L itself could be eliminated and the ratio of diameter to length brought in, so much the better. From what has already been stated, the same remark would apply to patent furnaces of the Purves-Brown and the Holmes classes; in fact, the results of experiments seem to show that even the constant C, viz., the strength coefficient, does not vary as the thickness, but appears to drop as the latter is increased; possibly the length and thickness are in some way so connected as to cause

of preventing change of form transversely resulting from racking stresses. It is not an easy matter to construct a large steamer of sufficient strength transversely, with an ordinary quantity of material, without having a second steel deck, or hold beams and stringers, to distribute the rigidity between the bulkheads so that there may be sufficient horizontal longitudinal strength.

A few years ago, when the writer was superintendent of a line of general cargo steamers and screw colliers, in which there were vessels having their engines amidships and others having them aft, the owners were so convinced that the after location was the best for their trade that they went to great expense in one steamer in moving the machinery from amidships to aft. The results in actual work justified the change.

In the writer's opinion, the most serious stresses are not the longitudinal hogging stresses, but rather those due to sagging and torsion, which alternately expand and compress the topsides and decks, such as would be developed when the vessel's centre of gravity has passed the momentary centre of buoyancy, as on the crest of a wave. The bow would then fall into a rising wave, while a large portion of the vessel amidships is wholly unsupported. These stresses tend to cause the decks amidships to rise and flatten, and also the topsides to pant. Hence arises the necessity for good transverse strength, which is fulfilled by large web-frames, firmly kneed or bracketed to the upper bottom and decks, as well as good longitudinal hold stringers to distribute the horizontal stresses among the web-frames and bulkheads.

Some very light steamers were built on the Lakes within a few years, and there was danger of more being constructed, but happily it has passed, for the present at least. Recourse has been had to a good deal of plate doubling, evidently for the increase of longitudinal strength, and it may have been needed for the topsides, but more strength is being added to the bottom than to the top. One vessel has had six keelsons and stringers added below the main deck, and other analogous additions have been made elsewhere, much to the credit of our ship-builders and owners.

It should not be forgotten that, although some of our tank tops are somewhat thin for the duties often imposed on them,

they are continuous. The bottom is, of course, which latter alone is the factor that causes the longitudinal neutral plane of Lake steamers to be as low down as 65% of the moulded depth below the gunwales, as may be seen by the calculation of moment of inertia for a screw-steamer $285' \times 40' \times 26'$.

Distance of neutral plane below gunwale . . .	17.2 ft.
Moment of inertia	46,041.12
Displacement at 17 ft. mean draught	4,720 tons.
Length on upper deck	285 ft.

Coef. of longitudinal strength $\frac{4720 \times 285 \times 17.2}{46041.12} = 50.29.$

Approximate bending-moment at the gunwale:

Ashore	50.29 tons per square inch.
Afloat	10.06 " " " "

It may console the owners as well as builders of *good* thin steamers, that the thin steamers are not the only ones which have shown signs of distress. Some of the very heavy vessels have suffered even more than the *good* thin ones.

It would seem that it is not so much an increase in shell-plating that is required, as greater strength in the framing, beams and stringers; and it is hardly necessary to say that the function of these—at any rate, the first—is to afford transverse strength. In many instances, the lower part of sheer-strake and topside plating are found severely strained, while the upper stringer-plates are not distressed. What can cause this except lack of transverse strength? Those vessels with the heaviest beams and frames have best stood the test of actual work.

Finally, a few words may be said relative to the materials of which the steamers are built, and their scantlings.

In the early days of steel-ship building, some bad steel was certainly put on the market. Some was so bad that, after incorporation into the hull, it had to be cut out. One experienced ship-builder has so little faith in the reliability of steel after it has been locally heated and flanged—and he appreciates the benefits of annealing—that he makes all his flanged

mean of the two conditions just mentioned might be near the truth.

If the ends are loose, the bending moment in inch pounds would be, $\frac{\text{load} \times \text{length of boiler in inches}}{8}$; and if fixed, $\frac{\text{load} \times \text{length in inches}}{24}$. Taking a stave 1″ wide, the moment of resistance would be, in inch-pounds, = (thickness of plate in inches)$^2 \times 1 \times$ tensile strength per square inch $\times$ .2886.

Assuming a mean value for the bending moment, it will be found on taking an example that the value of such a beam would be very little; in fact, a stave of a boiler 10 feet long with a shell plate 1″ thick is only good for $\frac{3}{8}$ lb. on the square inch if the tensile strength of the material is taken at 60,000 lbs. From reasoning such as what has gone before, I was in the habit of discarding the barrel view of the subject, and confining myself only to the ring until the present time.

Before proceeding to a third way of looking at the matter, I may mention that, a few years ago, Mr. Spence of Newcastle-on-Tyne had the audacity to suggest, in a paper he read before the North-East Coast Institution of Engineers and Shipbuilders, that the length of the boiler should be made a factor in calculating the resistance of the cylindrical shell to bursting. I have not followed Mr. Spence's arguments, but read some of the discussions with considerable interest, and noticed that he got very little support even from his fellow-engineers; further, a mathematician writing from Oxford University, after a most elaborate investigation, went so far as to say that the presence of the ends in a boiler assisted only to an infinitesimal degree when the length was within the limits which usually obtain in practice.

Let us now look upon the problem in a broad way, if possible free from preconceived ideas, giving due consideration to phenomena which are visible to our eyes nearly every day. If it is thought that such phenomena have a bearing on the subject, it is right that they should be investigated; if not, no harm is done in bringing them into prominence.

Many may have noticed that when a glass tube is heated in the middle to a full red heat, and the ends drawn away from each other, the tube contracts in diameter at the part where it is sufficiently hot to yield. That this phenomenon is

OPERATIONS OF STEAMER "MANOLA," 292′ × 40′ × 24½′.

(One of the Minnesota Fleet of Cleveland, Ohio.)

Per cent of operations to earnings	58.79
Earnings per ton per mile	.00078
Operating expense per ton per mile	.00046
Net earnings per ton per mile	.00032
Earnings per mile travelled	1.853
Operating expense per mile travelled	1.090
Net earnings per mile travelled	.763
Total miles travelled	50,584
Average miles travelled per day	227¼
Tons freight carried	71,170.69
Tons freight carried one mile	3,600,078,861
Average speed per hour light	12.72
Average speed per hour loaded	11.85
General average speed per hour	12.25
Total tons fuel used	5528
Average tons fuel used per trip	184.553
Average amount fuel per mile light........lbs.	209
Average amount fuel per mile loaded..... "	226
General average amount fuel per mile..... "	218
Average fuel per ton per mile..........oz.	1¼
Number of trips	30
Average size cargo....tons	2395.82
Average draught water Sault Canal, feet	14′ 7″—14′ 9″
Average time loading............hrs.	7¼
Average time unloading.......... "	12
Average time handling cargo...... "	19¼
Average tons loaded per hour	306.244
Average tons unloaded per hour	191.712
Average tons handled per hour	235.105
Actual time sailing..........days	175
Actual time in port.......... "	47
Actual time in commission... "	222
Per cent of time sailing	.7883
Per cent of time in port	.2117
Average number crew each trip	23
Average wages crew each trip	334.05
Average length of trip....days	7.396
Average mileage per trip	1686

Coal, short tons; cargo, long tons.

DISCUSSION ON COMPARISON OF THE TYPES OF STEAMERS ON THE GREAT LAKES WITH REGARD TO STRENGTH, EFFICIENCY, AND LOCATION OF MACHINERY.

Mr. John C. Kafer:—I would like to ask Mr. Oldham what he claims for the vessels constructed on the Lakes over those constructed on the Atlantic seaboard. Superiority has been claimed for the whaleback steamer as a carrier, but I am sure there are freight steamers running out of New York that carry their freight quite as economically per ton-mile as any of the whalebacks, besides being stronger and better fitted for the trade.

Mr. Oldham:—In reply to Mr. Kafer I may say that the comparison in my paper was not between lake steamers and ocean steamers, but between lake steamers and lake steamers; and I do not know that I could make such a comparison as Mr. Kafer suggests that would interest you. I know that they build very excellent vessels on the coast, and we build very excellent vessels on the Lakes, and I think that the two together will bear favorable comparison with any ships in the world.

Mr. Geo. W. Dickie:—One of the objects I had in coming to Chicago at the present time was to look into the lake shipping, and I have not made the acquaintance yet of any number of the gentlemen engaged in this work here; but I just want to say that I am going to be here a little while, and I am going to Cleveland, and I want to see all that can be seen in lake shipping. I am very much interested in it, and it is a question of vast importance. The enormous amount of shipping that has been developed on these Great Lakes, the amount of freight, as I notice by this table, is something that to one coming from the seaboard to the centre of the country is a revelation, to find that this business has assumed such enormous proportions. I trust that those interested will not let me go away without being a little better posted than I am now on lake shipping.

Mr. Oldham:—In endeavoring to be brief, I hope I have not

been discourteous in replying to Mr. Kafer. I can only say this, that all I know at the present moment is in this paper, and therefore it would be useless waste of your time for me to repeat it; but if there is anything specific that Mr. Kafer wishes to know, or any of the gentlemen, I will be pleased to answer.

CHAIRMAN LORING:—I think Mr. Kafer wished you to give a comparison between the lake steamers and the ocean steamers.

MR. OLDHAM:—On the seaboard I think you are very largely governed by the registration societies. Such has not been the case on these Lakes. The registration societies are doing but little in that way; but really many of our vessels are built in advance of all the rules as they are published by our registration societies, and I am not sure that they are any the worse for that. I think it is rather a good thing to give the ship-builder a free hand,—to be supervised in some degree, to be sure, to see that there is sufficient material there; but at any rate I am certain this is true, that the freer the ship-builder is, the greater variety we will have, and the sooner will we get at the best type of ship.

MR. E. PLATT STRATTON:—As representing one of the registration societies of this country, I would ask if the steamships "Gilcher" and "Western Reserve" were built under the rules of any registration society.

MR. OLDHAM:—In reply I may say that so far as I know they were not built under the rules of any registration society; but never having been on board of the "Gilcher," and only once for an hour or two on board of the "Western Reserve," and that some two or three years before she was lost, I cannot speak with authority.

MR. OLDHAM (reply in writing after the meeting):—In reply to my friends, Mr. Dickie and Mr. Kafer, I may say,—and that at the risk of repeating a portion of my paper,—that our modern lake tonnage is composed of two great classes, viz., dead-weight carriers, principally engaged in the iron-ore trade; and general cargo steamers, chiefly owned or controlled by the great railroad companies; and the carrying capacity of the latter class amounts to about one hundred thousand tons.

As regards the models of these steamers, they are not very dissimilar to ordinary ocean steamers, except that they are somewhat shallower in proportion to their breadth, the average depth being about 65 per cent of the mean breadth, in comparison with 70 per cent as the ratio obtaining in ocean steamers. Then the rise of floor in our steamers is about a quarter of an inch per foot half-breadth of beam, this being about one third of the average dead-rise in ocean steamers.

The displacement coefficient of lake steamers is about .81 against .78 in coast steamers. Our steamers are generally fitted with balanced rudders; and when these are properly proportioned no power is required to turn the rudder beyond that necessary to move the water, and to overcome the *vis inertia* and friction of the one pintle and the bearing on deck or at the counter. Should it be thought that these rudders may be weak laterally, I may state that the White Star royal mail steamer "Britannic" had no keel-piece abaft of her propeller-post; consequently her rudder was altogether unsupported at the heel, and it gave no trouble, for that steamer was classed by the "Veritas" after my survey.

I consider the balanced rudder a great improvement on the ordinary ocean type; indeed, that has apparently been proved, for we have two very large steamers here which have recently had their rudders changed from the ordinary coast type to the usual lake balanced type, and the owners claim a great improvement as resulting from the change. These rudders may get knocked largely out of line without disablement, whereas with two or three pintles connected to the stern-post the rudder cannot be turned when so injured. Our stern-bearings are adjustable with the ship afloat; this is a necessity here, for lake steamers frequently run for two or three years without going into dry-dock.

The lake steamers have from eight to ten cargo hatchways spaced 24 feet apart centre to centre, the length of these hatchways being about 70 per cent of the breadth of the vessel, by 8 feet wide in a fore-and-aft direction. Such hatchways might be found advantageous in coasting steamers engaged in the ore, coal, or grain trades, when they are regularly employed in these trades.

Our boilers being raised almost up to the main deck is a necessity with the engines right aft, as the vessel would be "by the head" when loaded with grain or coal if there were no space under the boilers for cargo.

Of course, with the same height of stack above deck, the boilers being raised above the level of the sea ought to be harder to fire; but we think this is not so, and it may be accounted for by the large boiler-house and good ventilation. But however that may be, the engineers and firemen have a strong predilection for the raised stokehold, which is also adopted here, even when the boilers are located about midships.

Another advantage of the raised stokehold is that the boilers can be emptied overboard without blowing down.

I think the cabins on lake steamers are peculiarly large and handsome for cargo boats; but it may be that these will soon be

greatly reduced, as some of our ship-owners appear to be disinclined to continue providing accommodation and provision for some ten or twelve guests during the lake season of navigation. A strange feature of the accommodation is that all the sleeping-berths are placed athwartships.

As regards the typical ore-carrier, the tendency is to make her shallower—to reduce the freeboard in fact; and we now have steel steamers of about sixteen times their depth in length. Of course in such steamers there should certainly be no reduction of scantlings at their upper deck; this, however, has been carefully provided for in the Great Lakes Register of Shipping Rules.

There is another class of lake vessels which are quite a contrast to the above, for they are simple in the extreme, and having abnormal tumble-home they probably roll easier than the ordinary steamers, which have their extreme breadth almost as high as the upper deck. Such vessels when heeled to an angle of 36° have a righting-moment of 8000 foot-tons. A steamer of similar displacement and proportions but with elliptical topsides has only 6250 foot-tons righting-moment at the same degree of inclination, but even less than this would be desirable with a sufficient range of stability.

The Minnesota fleet and many other steamers regularly steam a distance of over 1600 miles and load and discharge 3000 tons of cargo all within the week, including stoppages at the Sault Ste. Marie Canal, and "slowing down" over Lake St. Clair and other shallow waters.

The officers and crew keep "watch and watch," or six hours on deck and six below.

But little ingenuity has been displayed in the arrangement of the weather-decks on these lakes. Such extraordinary conceptions as raised fore-decks, long quarter-decks, and other "well" deck arrangements, are almost unknown to lake practice; our steamers are simple flush-deck vessels.

I am aware that with some artistic designing and artful loading an advantage may be achieved over the tonnage laws and the load-line act by raising the decks by steps of 3½ to 4 feet each over the after and midships body of the vessel; and then by loading sufficiently "by the heel" the steamer may have a respectable nominal freeboard at the lowest exposed part of her main (weather) deck, while the load-line disk at mid length is actually submerged. Some eight years ago I illustrated this at an important wreck inquiry into the loss of the S.S. "Bendigo," and I think the drawing proved somewhat interesting, if not startling. (See cut opposite).

So, notwithstanding some little difficulty in making a flush-deck

In the Appendix is also added a summary of certain experiments made to ascertain the holding power of tubes under various conditions. As they are all made in the cold state they may not be of much practical value, but they are certainly very interesting, and might form some guide at least as to what would be necessary for tubes in the outside tube plates not exposed to fire.

Now, gentlemen, I have completed my review, and I trust that those who join in the discussion will not only deal with the points in the several sections which have been considered worthy of special notice in the review, but will also dissect each section more exhaustively; raising questions and making suggestions either not thought of or which for other reasons have not been mentioned.

As far as material goes, it may be said that the burden of the review is "extreme ductility." If it should not be so for boilers as we find them at present constructed without machined joints and the requirements of the fitting-shop, it will be interesting and instructive to hear what the advocates of the other side have to say.

As touching the expressions for scantlings for the various parts of which boilers are composed, the review may seem to lean to those of the British Board of Trade. Considering that they are the pioneer rules, and have still by far the largest scope, and considering that they are largely founded on carefully conducted experiments, is this to be wondered at? Is the wonder not, rather, that they have not been generally adopted by all the other bodies, with such changes in constants as might after careful investigation have been thought safe and prudent.

APPENDIX I.

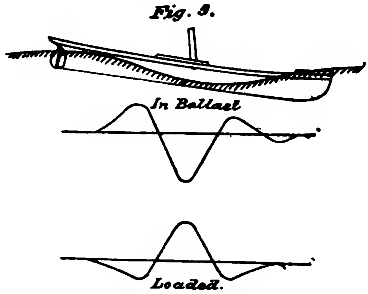
EXPERIMENTS ON THE HOLDING POWER OF BOILER TUBES.

[Extracted from the pages of *Engineering*.]

TABLE I.—RESULTS OF EXPERIMENTS ON BRASS TUBES, CONDUCTED AT WASHINGTON NAVY YARD, BY CHIEF ENGINEER W. H. SHOCK, U.S.N.

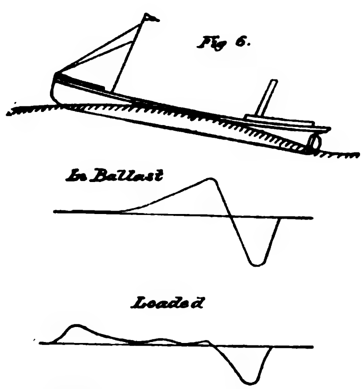
Number of Specimen.	Outside Diameter.	Area of Section.	Diameter after Experiment.	Thickness of Tube-plate.	Method of Fastening.	Kind of Ferrule ($\frac{1}{2}$ by $1\frac{1}{4}$).	Strain in Pounds.
	in.	sq. in.		in.			
1	2.5	.9	2.42	$\frac{3}{4}$	Prosser	Iron	28,650
2	2.5	.9	2.41	$\frac{3}{4}$	"	"	30,200
3	2.5	.9	2.35	$\frac{3}{4}$	Dudgeon	"	32,750
4	2.5	.9	2.34	$\frac{3}{4}$	"	"	36,000
5	2.5	.9	2.50	$\frac{1}{2}$	"	None	21,150
6	2.5	.9	2.44	$\frac{1}{2}$	Prosser	"	12,000
7	2.5	.9	2.44	$\frac{1}{2}$	"	Iron	27,800
8	2.5	.9	2.25	$\frac{1}{2}$	Dudgeon	"	46,000
9	2.5	.9	2.31	$\frac{5}{8}$	"	"	39,300
10	2.5	.9	2.44	$\frac{5}{8}$	"	"	36,000
11	2.5	.9	2.50	$\frac{5}{8}$	Prosser	"	25,300
12	2.5	.9	2.50	$\frac{5}{8}$	"	"	26,400
13	2.5	.9	2.50	$\frac{3}{4}$	Nut $\frac{3}{4}$ in. thick	None	30,450
14	2.5	.9	2.50	$\frac{3}{4}$	"	"	27,000
15	2.5	.9	2.50	$\frac{3}{4}$	"	Iron	40,130
16	2.5	.9	2.50	$\frac{3}{4}$	"	"	38,600
17	2.6	1.33	2.60	$\frac{3}{4}$	"	None	22,000
18	2.6	1.33	2.60	$\frac{3}{4}$	"	"	21,400
19	2.6	1.33	2.60	$\frac{3}{4}$	"	Iron	39,850
20	2.6	1.33	2.40	$\frac{3}{4}$	"	"	41,650
21	2.5	.9	2.50	$\frac{3}{4}$	Dudgeon	None	7,650
22	2.5	.9	2.50	$\frac{3}{4}$	"	"	5,850
23	2.5	.9	2.50	$\frac{3}{4}$	"	Iron	14,460
24	2.5	.9	2.50	$\frac{3}{4}$	"	"	13,850
25	2.5	.9	2.50	$\frac{3}{4}$	"	None	8,300
26	2.5	.9	2.50	$\frac{3}{4}$	"	"	8,150
27	2.5	.9	2.50	$\frac{3}{4}$	"	Iron	14,250
28	2.5	.9	2.50	$\frac{3}{4}$	"	"	14,550
29	2.5	.9	2.50	$\frac{3}{4}$	Prosser	None	14,450
30	2.5	.9	2.50	$\frac{3}{4}$	"	"	15,000
31	2.5	.9	2.50	$\frac{3}{4}$	Dudgeon	"	17,075
32	2.5	.9	2.50	$\frac{3}{4}$	"	"	21,825
33	2.5	.9	2.50	$\frac{3}{4}$	"	Brass	32,250
34	2.5	.9	2.50	$\frac{3}{4}$	"	"	31,400
35	2.5	.9	2.50	$\frac{3}{4}$	Prosser	"	22,750
36	2.5	.9	2.50	$\frac{3}{4}$	"	"	22,950
37	2.5	.9	2.50	$\frac{3}{4}$	"	"	17,350
38	2.5	.9	2.50	$\frac{3}{4}$	"	"	17,400
39	2.5	.9	2.50	$\frac{3}{4}$	Dudgeon	"	24,800
40	2.5	.9	2.50	$\frac{3}{4}$	"	"	23,600
41	2.5	.9	2.50	$\frac{3}{4}$	Prosser	None	9,800
42	2.5	.9	2.50	$\frac{3}{4}$	"	"	10,850
43	2.5	.9	2.50	$\frac{3}{4}$	Dudgeon	"	23,890
44	2.5	.9	2.50	$\frac{3}{4}$	"	"	22,250
45	2.5	.9	2.50	$\frac{3}{4}$	"	Brass	29,800
46	2.5	.9	2.50	$\frac{3}{4}$	"	"	27,550
47	2.5	.9	2.50	$\frac{3}{4}$	Prosser	"	15,250
47	2.5	.9	2.50	$\frac{3}{4}$	"	"	20,250

Fig. 5.



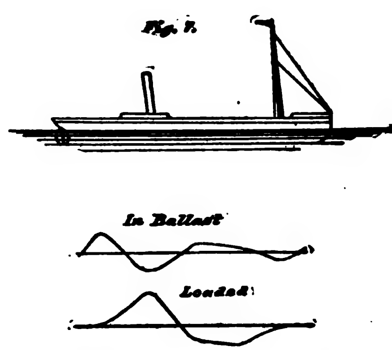
Ballast.				Loaded			
Weight	Buoyancy	Weight Excess	Buoyancy Excess	Weight	Buoyancy	Weight Excess	Buoyancy Excess
255	257		2	660	665		5
260	428		168	1200	1026	174	
1015	590	425		735	1085		350
480	730		250	1200	1024	176	
465	470		5	665	660	5	
2475	2475	425	425	4460	4460	355	355

Fig 6.



Ballast				Loaded			
Weight	Buoyancy	Weight Excess	Buoyancy Excess	Weight	Buoyancy	Weight Excess	Buoyancy Excess
257	250	7		402	660		258
400	428		28	1000	1026		26
460	590		130	1050	1085		35
410	730		320	1000	1026		26
948	477	471		1008	665	343	
2475	2.475	478	478	4460	4460	343	343

Fig. 7.



Engines in Medium Situation.

Ballast				Loaded			
Weight	Buoyancy	Weight Excess	Buoyancy Excess	Weight	Buoyancy	Weight Excess	Buoyancy Excess
355	257	98		660	660		
385	428		43	1200	1026	174	
640	590		50	1200	1085	115	
835	750	165		735	1024		289
300	470		170	665	665		
2475	2475	265	265	4460	4460	289	289

TABLE II. (*Continued*).—RESULTS OF MESSRS. YARROW & CO.'S EXPERIMENTS.

Number of Specimen.	Description.	Method of Fastening.	Method of Giving Way.	Pull in Lbs.	Remarks.
1801	Taper steel tube $2\frac{3}{16}$ in. outside diameter, reduced to 2 in., $\frac{1}{8}$ in. thick	Hole in tube-plate coned to same taper as mandrel of expander, round edge, bead, no ferrule	Tube pulled through and partly broken	25,884	
1802	Parallel steel tube 2 in. outside diameter, $\frac{1}{8}$ in. thick	Ditto ditto	Tube partly pulled through and partly broken	25,158	
1786	Ditto ditto	Ditto ditto	Ditto	23,898	
1787	Taper steel tube $2\frac{3}{16}$ in. outside diameter, reduced to 2 in., $\frac{1}{8}$ in. thick	Ditto ditto	Ditto	28,066	
1803	Ditto ditto	Ditto ditto	Ditto	22,494	
1804	Parallel steel tube 2 in. outside diameter, $\frac{1}{8}$ in. thick	Parallel hole through tube-plate, countersunk $\frac{1}{4}$ in., no ferrule	Ditto	21,794	
1788	Ditto ditto	Ditto ditto	Ditto	20,814	
1805	Taper steel tube $2\frac{3}{16}$ in. outside diameter, reduced to 2 in., $\frac{1}{8}$ in. thick	Ditto ditto	Ditto	23,067	
1789	Ditto ditto	Ditto ditto	Tube broken in tube-plate	32,708	
1790	Parallel steel tube 2 in. outside diameter, $\frac{1}{8}$ in. thick	Parallel hole through tube-plate, countersunk $\frac{3}{8}$ in., with bell-mouthed ferrule	Tube pulled asunder	32,957	
1806	Ditto ditto	Ditto ditto	Ditto	26,038	Mean pull on above two tubes is 29,497 lbs.
1791	Taper steel tube $2\frac{3}{16}$ in. outside diameter, reduced to 2 in., $\frac{1}{8}$ in. thick	Parallel hole through tube-plate, countersunk $\frac{3}{8}$ in., no ferrule	Ditto	41,715	
1807	Ditto ditto	Ditto ditto	Tube partly pulled through and partly broken	37,432	Mean pull on the above two tubes = 39,573 lbs.
1232	Taper steel tube $2\frac{1}{4}$ in. outside diameter, reduced to 2 in.	Parallel hole through tube-plate, countersunk $\frac{1}{4}$ in., no ferrule	Tube pulled through	19,012	
1233	Ditto ditto	Parallel hole through tube-plate, countersunk $\frac{3}{8}$ in., no ferrule	Ditto	18,222	

TABLE III.—EXPERIMENTS ON 4-IN. AND 5-IN. TUBES.

Number of Specimen.	Description.	Method of Fastening.	Method of Giving Way.	Pull in Lbs.	Remarks.
8022	Steel tube 4 in. in diameter, .15 in. thick	Tube tightly expanded in ordinary way and ferrule driven in as usual	Tube pulled through	63,920	
8023	Ditto ditto	Ditto ditto	Ditto ditto	45,040	In this case the ferrule was driven in somewhat further
6556	Iron tube 4 in. in diameter	Tube expanded into plate in ordinary way and with usual amount of tightness, beaded over	At a load of 15 tons there were slight signs of the beading giving way, at 15.9 tons the plug was pushed through about $\frac{1}{16}$. After this the plug was pushed through by gradually decreasing load, coming out at last at a load of 8 tons	35,610	Intended to represent the ordinary conditions of good workmanship
6557	Ditto ditto	Tube expanded only slightly, just sufficient to allow of beading over	At a load of 16.4 tons beading gave slightly, at 19 tons the plug slipped, and was pushed through by a load of 12 tons	42,560	Intended to represent a leaky tube held only by its beading
6558	Ditto ditto	Tube expanded tightly, not beaded, the end projecting $\frac{1}{8}$ in. beyond plate	At a load of 11.9 tons tube slipped in plate, then it stood a load of 4 tons, and finally was pushed out at 1 ton	26,210	These experiments show effect of increase of diameter. In the first, however, the hole in tube-plate calipered a shade less on the outside of the plate than on the inside, so that the grip lessened as the tube was drawn out. With the second tube the reverse was the case
6559	Iron tube 5 in. in diameter	Tube expanded tightly, not beaded	At a load of 14 tons tube slipped in plate. Then it stood 12 tons, and on the load being again carried up to 14 tons it slipped again, and was finally pushed out by loads decreasing from 8 to $1\frac{1}{4}$ tons	31,360	
6903	Steel tube 4 in. in diameter	Tightly expanded, beaded in the ordinary way	Pushed clean through plate quite suddenly, beading broke off clean all round	68,040	
6904	Ditto ditto	Ditto ditto	Ditto ditto	61,600	
6905	Ditto ditto	Well expanded only	Tube pushed through plate	20,720	
6646	Iron tube 4 in. in diameter	Same tube as 6557, the plug having been made good	Beading came right off	34,560	
6647	Ditto ditto	Same tube as 6558, the plug having been made good	Beading drew through plate and tore off	36,150	
6648	Ditto ditto	The tube hole tightly expanded, countersunk, and beaded	Beading tore off suddenly	38,850	
6649	Ditto ditto	Same as above, but bead slightly imperfect	....	37,150	
6650	Ditto ditto	Slightly expanded, only countersunk and beaded	....	31,550	
6651	Ditto ditto	Tube expanded, not countersunk, and bead $\frac{1}{8}$ in. clear of plate	Beading drew off	28,350	

TABLE IV.—RESULTS OF EXPERIMENTS ON THE TENSILE STRENGTH OF TUBES USED BY MESSRS. YARROW.

Number.	Diameter.	Sectional Area.	Ultimate Tensile Strength.		Fractured.		Difference.		Extension on Ten Inches.	Appearance of Fracture.
			Total.	Per Square Inch.	Diameter.	Sectional Area.	Area.	Per Cent.		
	ins.	sq. in.	lbs.						per cent.	
1780	2.00	....	......	......	1.67					
2	1.77	.681	35,227	51,728	1.43	.471	.210	30.8	23.5	Fibrous
1792	2.00	....	......	......	1.76					
2	1.79	.630	34,520	54,793	1.59	.448	.182	28.8	21.9	"
1779	2.30	....	......	......	2.04					
2	2.06	.832	42,615	51,780	1.84	.610	.213	25.8	23.8	"
1798	2.30	....	......	......	1.81					
2	2.08	.759	40,840	53,807	1.65	.434	.325	42.8	26.4	"
1796	2.00	....	......	......	1.70					
2	1.79	.630	29,880	47,428	1.53	.433	.197	31.2	19.7	"
1808	2.00	....	......	......	1.62					
2	1.79	.630	32,042	50,860	1.45	.409	.221	35.0	19.8	"
1795	2.30	....	......	......	1.81					
2	2.07	.791	38,530	48,710	1.66	.409	.382	48.2	25.2	"
1809	2.30	....	......	......	1.86					
2	2.10	.691	35,920	51,982	1.70	.447	.244	35.3	26.2	"

TABLE V.—EXPERIMENTS ON MATERIALS OF 4-IN. TUBES.

Nature of Specimen.	Number.	Dimensions. Breadth.	Dimensions. Thickness.	Dimensions. Area.	Elastic Limit. Tons per Sq. Inch.	Breaking Load. Pounds per Square Inch.	Breaking Load. Tons per Square Inch.	Length of Specimen.	Extension.	Reduction of Area.	Remarks.
		in.	in.	sq. in.				in.	p. ct.	p. ct.	
Specimen cut from wrought-iron tube previously tested in tube-plate	6648_2	0.975	0.146	0.142	20.45	56,900	25.40	1.5	14.7	19.0	Silky and laminated fracture
Ditto ditto	6648_3	0.993	0.153	0.152	17.84	52,590	23.48	1.5	12.0	17.6	Silky and laminated fracture, but about 10 per cent crystalline
Specimen prepared from broken beading of steel tube previously tested in plate	6904_3	0.123	.070	.009	....	88,840	39.67	2.0	15.0	26.8	Silky fracture annealed
Ditto ditto	6904_4	.143	.058	.008	....	88,020	39.30	...	....	31.3	Ditto ditto
Ditto ditto	6903_1	....	....	about .0015	....	101,000	about 45.00	....	....	....	Pieces too rough to accurately measure, hence no reduction or extension taken (both annealed)
Ditto ditto	6903_6	....	....	about .0015	....	82,160	about 36.90	....	....	....	
Specimen cut from steel tube previously tested in plate	6903_2	1.012	.143	.145	24.28	72,980	32.58	2.0	16.0	31.7	Fracture silky, a trace of lamination with crystals
Ditto ditto	6903_3	1.012	.145	.147	26.41	79,628	35.54	2.0	18.5	45.5	Fracture finely silky
Specimen cut ringwise from expanded part of steel tube previously tested in plate	6904_1	.321	.124	.040	....	82,080	36.62	6.0	2.5	53.8	Fracture silky, somewhat granular in centre (unannealed)
Specimen cut ringwise from plain part of steel tube previously tested in plate	6904_2	.303	.146	.044	24.72	68,040	30.37	6.0	10.2	56.4	Fracture finely silky (unannealed)

RESULTS OF EXPERIMENTS ON VISIBLE SLIP IN DOUBLE-RIVETED JOINTS.

Lap	⅝	plate	with	.8	diameter	holes,	hand	riveted,	slipping	at	33%	of breaking	load.
Lap	⅝	"	"	.8	"	"	machine	"	"	"	43%	"	"
Double butt	⅝	"	"	.7	"	"	"	"	"	"	71%	"	"
Lap	¾	"	"	1.1	"	"	hand	"	"	"	30%	"	"
Lap	¾	"	"	1.1	"	"	machine	"	"	"	32%	"	"
Butt	¾	"	"	1.1	"	"	"	"	"	"	49%	"	"
Lap	¾	"	"	1.6	"	"	"	"	"	"	29%	"	"
Double butt	¾	"	"	1.6	"	"	"	"	"	"	40%	"	"
Lap	1	"	"	1.3	"	"	"	"	"	"	26%	"	"
Lap	1	"	"	1.75	"	"	"	"	"	"	34%	"	"
Double butt	1	"	"	1.3	"	"	"	"	"	"	44%	"	"
Lap	⅝	"	"	.8	"	"	hand	"	"	"	25%	"	"
Double butt	⅝	"	"	.7	"	"	"	"	"	"	34%	"	"
Lap	¾	"	"	1.1	"	"	"	"	"	"	21%	"	"
Double butt	¾	"	"	1.1	"	"	"	"	"	"	13%	"	"
Lap	⅝	"	"	.8	"	"	machine	"	"	"	50%	"	"
Double butt	⅝	"	"	.7	"	"	"	"	"	"	67%	"	"
Lap	¾	"	"	1.1	"	"	"	"	"	"	33%	"	"
Double butt	¾	"	"	1.1	"	"	"	"	"	"	31%	"	"

It would appear, that, provided the hydraulic pressure is sufficient to properly close the rivet, any increase of pressure is no advantage as far as obviating slipping goes.

The amount of metal in the heads seems important, a good substantial head being an advantage in drawing the joints tight when cooling.

The crushing pressure on the projected area of the rivet at fracturing load should not much exceed 40 tons per square inch; if this is much exceeded, stresses are brought to bear on the rivets which cause them to give way much before their calculated shearing load; with a crushing pressure of 45 to 50 tons, the rivets may shear at 16 or 18 tons per square inch, instead of 22 or 23 tons.

The above experiments (Table I), made in the Washington Navy Yard, show that with 2¼ brass tubes, in no case was the holding power less, roughly speaking, than 6000 lbs., whilst the average was upwards of 20,000 lbs. It was further shown that with these tubes nuts were superfluous, quite as good results being obtained with tubes simply expanded into the tube-plate and fitted with a ferrule. When nuts were fitted it was shown that they drew off without injuring the threads.

Turning to Messrs. Yarrow's experiments (Table II) on iron and steel tubes of 2″ to 2½″ diameter, it will be observed that the first 5 tubes gave way on an average of 23,740 lbs., which, from Table IV, would appear to be about ⅔ the ultimate strength of the tubes themselves. In all these cases the hole through the tube-plate was parallel with a sharp edge to it, and a ferrule was driven into the tube. The next two cases, viz., numbers 931 and 1238, differ only from the above in that the edges of the hole were rounded off slightly, but it is impossible to say positively whether this had any effect on the holding power, as though the mean pull required is slightly less, the figures for No. 1238 look doubtful, as if the tube had been insufficiently expanded; even taking 931 as the proper result to be expected from the rounding of the edges of the hole, the increase as compared with the result of the preceding tubes is probably too small to justify the additional work.

The next 5 tubes are interesting, as they were made under the same conditions as the first 5, with the exception that in this case the ferrule was omitted, the tubes being simply expanded into the plates. The mean pull required

was 15,270 lbs., or considerably less than half the ultimate strength of the tubes.

The addition of ferrules, therefore, to tubes of this diameter may be expected to increase their holding power when cold and newly expanded 55%.

Next, proceeding to Nos. 1237, 930, 1236, and 1234, we see the effect of beading the tubes, the holes through the plate being parallel and ferrules omitted. The mean of the first 3, which are tubes of the same kind, gives 26,876 lbs. as their holding power, under these conditions, as compared with 23,740 lbs. for the tubes fitted with ferrules only. This high figure is, however, mainly due to the exceptional case of 930, where the holding power is greater than the average strength of the tubes themselves, as given in Table IV.

The true mean is probably more about 21,000 lbs.

The next few results seem to show that it is disadvantageous to cone the hole through the tube-plate, unless its sharp edge is removed, as the results are much worse than those obtained with parallel holes, the mean pull being but 16,031 lbs., the experiments being made with tubes expanded and ferruled but not beaded over.

Nos. 1782, 1783, 1798, and 1799 refer to experiments on tubes expanded into tapered holes, beaded over and fitted with ferrules; the net result is that the holding power is, for the size experimented on, about $\frac{2}{3}$ of the tensile strength of the tube, the mean pull being 28,797 lbs.

With tubes expanded into tapered holes and simply beaded over, better results were obtained than with ferrules: as indicated in the Table; in these cases, however, the sharp edge of the hole was rounded off, which appears in general to have a good effect.

Nos. 1804, 1788, 1805, and 1789 show some good results obtained by countersinking the tube-plate $\frac{1}{4}''$ and expanding the tube into it. The mean pull for the 2″ tubes is 21,269 lbs., but for the $2\frac{1}{16}''$ taper tubes the results are inconsistent, probably due to differences of workmanship.

By driving bell-mouth ferrules into the tubes still better results were obtained, the mean figures for 2 parallel tubes being 29,497 lbs., the tubes pulling asunder in both cases: the fastening, therefore, was stronger than the tube.

The value of the plan of countersinking the tube-plate is, however, rather discounted by experiments 1282 and 1283, as in these two cases the tubes pulled through at a comparatively low figure; and with the results with the larger tubes already referred to, this seems to show that the workmen required to exercise more care in their work. The difference between these two experiments and the couple immediately preceding is very remarkable, and difficult to account for, except on the supposition of inferior workmanship.

Turning to Table III, which records the results made for *Engineering*, by Prof. Kennedy, we find, from a comparison of the specimens Nos. 6558 and 6559, that in the case of tubes, respectively 4″ and 5″ diameter, of the same thickness, and fixed in the same way, the holding power is apparently nearly proportional to the diameter. The number of experiments is, however, too few to allow of this deduction being definitely drawn.

Steel tubes, *when cold, freshly expanded*, seem to hold better than iron ones, though No. 6905 warns us to be cautious in generalizing.

Considering the experiments as a whole, it will be seen, that in no case with the larger tubes did the fastening prove as strong as the tube itself.

In one particular the experiments are incomplete, as it is impossible to re-

produce on a machine the racking the tubes get by the expansion of a boiler, as it is heated up and cooled down again, and it is quite possible, therefore, that the fastening giving the best results on the testing machine may not prove so efficient in practice.

In the experiments on the beaded tubes, recorded in Table III, some interesting results were obtained, to which it may be worth while to draw attention. No. 6557 shows the total holding power due to the beading alone; this specimen was specially prepared to represent the case of a leaky tube which had become comparatively loose in the hole, and which was depending upon the bead alone for its sufficiency as a stay. This tube stood a strain of 42,500 lbs., when the experiment was terminated by the plug at the other end of the tube being forced out.

In the case of No. 6903, when the tube was both tightly expanded and beaded, the resistance obtained, namely, 68,040 lbs., was approximately equal to the sum of the resistances obtained in samples Nos. 6557 and 6558, in one of which the tube was barely fixed in the hole by the expander, while on the other it was tightly expanded, but not beaded over.

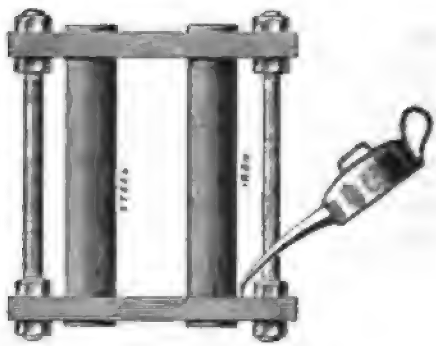
N. B.—It should be noted that the experiments were all made under the cold condition, so that references should be made with caution, the circumstances in practice being very different, especially when there is scale on the tube-plates, or when the tube-plates are thick and subject to intense heat.

APPENDIX II.

IRON *v.* STEEL BOILER-TUBES.

IN a recent article on the failure of Navy boilers, we made reference to certain experiments which had been carried out in order to test the relative efficiencies of iron and steel as materials for the construction of boiler-tubes. By the courtesy of Mr. A. Blechynden, of Barrow, we are now able to put before our readers some of the particulars of investigations undertaken by that gentleman. Mr. Blechynden prefers iron tubes to those of steel, but how far he would go in attributing the leaky-tube defect to the use of steel tubes we are not aware. It appears, however, that the results of his experiments would warrant him in going a considerable distance in this direction. The first test consisted of heating and cooling two tubes, one of wrought-iron and the other of steel. Both tubes were $2\frac{3}{4}$ in. in diameter and .16 in. thickness of metal. At a temperature of 46 deg. Fahr., the length of both the steel and the iron tube was 55.495 in. When heated to 186 deg. Fahr., the length of the steel tube was 55.547 in., and of the iron tube 55.543 in. The tubes were put in the same furnace, made red-hot, and then dipped in water. The length was then gauged at a temperature of 46 deg. Fahr., and that of the steel tube was found to be 55.488 in., and that of the iron tube 55.492 in. Upon the process being repeated the steel tube was found to be 55.457 in. long, and the iron tube 55.4885 in. A third heating and cooling brought the steel tube to 55.44075 in. long, and the iron tube to 55.482 in. long. The tests of both tubes were conducted simultaneously, and every care was taken to make them exactly alike. It will be seen that the total contraction of the steel tube, after the third cooling, was 0.05425 in., and of the iron tube 0.01300 in. The steel was Siemens-Martin, such as is generally used for tubes for Admiralty boilers. The iron was B.B. quality, Scotch make. The next test was made by putting two tubes into a pair of plates bolted together, as shown in the annexed sketch. Each hole was rimered with the same bit, and each tube end turned to the same gauge and rolled by the same man. The diameter of the tubes was $2\frac{3}{4}$ in., each being of

the same thickness. The steel was Siemens-Martin, made to Admiralty requirements. The iron was B.B. quality, ordinary Scotch make. The whole was heated in a furnace to a dull red heat, and dropped into water of about 100 deg. Fahr. After the structure was cooled it was found that the steel tube was so slack in the hole that when water was poured upon the joint, as shown, it ran between the plate and the tube. The iron tube was tight.



NAVY BOILERS.

(A letter to the editor of *Engineering*.)

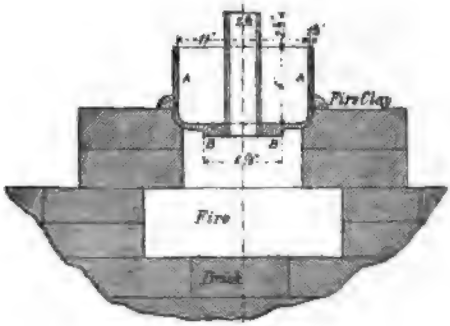
SIR,—Although little may be known of the arrangement of Admiralty boilers, it is notorious that much trouble has been caused by leakage of tubes under forced draught, a phenomenon that does not show itself in boilers in the merchant service when so worked.

Several causes have been suggested, and amongst others Mr. Yarrow suggested that the leaky-tube difficulty may be due, at least in part, to the thickness of the tube-plates. This led me to make some experiments on the subject, which, although they are not of a sufficiently refined nature to be absolutely conclusive, may not be without interest to many of my brother engineers.

For the sake of simplicity the experiments were made in an open boiler over a smith's fire. The experiments did not represent the actual condition of a boiler on board ship: firstly, because the temperature of the fire upon the end of the tube and on the tube-plate was higher than it would be even with forced draught; secondly, the experiments were

made under the atmospheric pressure, or, in other words, the boiler was open to the atmosphere at the top; thirdly, there was only one tube and perfect access of water to the neck of it and to the inner surface of the tube-plate.

The apparatus I used is shown in the annexed sketch. *AA* was a malleable-iron dish, supported on brickwork with a fire below blown by a couple of tuyeres—in fact, erected on



one of the smithy hearths and blown by the smithy blast. Fixed in the bottom of it was a steel tube 2½ in. in diameter, part of a tube got for the boilers of H.M.S. "Gibraltar." The lower end of this tube was turned, extended through the thickness of the tube-plate, and fixed by being expanded in the tube-hole in the usual way.

Half into the tube and half into the tube-plate three plugs of fusible metal were inserted, one of tin, one of lead, and one of antimony.

When the experiments began, the part of the plate into which the tube was fixed was 2¾ in. thick. At each successive experiment the thickness of this part, representing the tube-plate, was reduced by turning a certain amount off it.

As the water evaporated it was simply made up by slowly pouring in a little at the open top.

I will now describe the successive experiments in order, commencing with the plate 2¾ in. thick.

Experiment 1.—After the water was boiled for half an hour, the dish was lifted off the fire with the water in it, and the outer portion of the thick part of the bottom or tube plate was found to be red-hot.

The tin and lead plugs were melted out, but the plug of antimony was intact.

Experiment 2.—The thickness of the portion of the plate in which the tube was fixed was reduced to 1¾ in. by 1 in. being turned off it, and three new plugs of tin, lead, and antimony fitted as before.

The basin was replaced on the brickwork and subjected to the full heat of the fire for three-quarters of an hour.

When lifted off the fire, the water still in it, the plate was not visibly red-hot, but the tin and lead plugs were melted, though the plug of antimony was not.

Experiment 3.—The thick part of the plate in which the tube was fixed was now reduced to 1¼ in., and plugs put in same as before, the vessel replaced on the brickwork and submitted to the action of the fire for three-quarters of an hour.

On being removed it was found that the tin plug was fused, but both the lead and antimony remained quite sound.

Experiment 4.—This trial was a simple repetition of the last, the only difference being that a small quantity of oil was added to the water.

On the basin being lifted off the fire both the tin and lead plugs were found to be fused. This is remarkable inasmuch as when the water was emptied out of the basin no traces of decomposed oil were visible.

Experiment 5.—The thickness of the bottom of the vessel was now reduced to 1 in., and three plugs inserted same as before.

In this case, when the vessel was removed from the fire, the tin plug was found to be completely melted, the lead and antimony plugs remaining quite sound.

Experiment 6.—The thickness of the part of the bottom in which the tube was fixed was this time reduced to a mean of $\frac{13}{16}$ in., and two tin plugs and one of lead inserted in the same way as before.

As in the previous trials, the vessel was placed on the fire for three-quarters of an hour, and on lifting it off one of the tin plugs was found to be melted, the other not, and the lead plug was perfectly sound.

It so happened that the turner in reducing the thickness of the bottom left it ¾ in. at one side and $\frac{13}{16}$ in. at the oppo-

site side. The tin plug which melted was in the part that was $\frac{15}{16}$ in. thick, while the tin plug in the part $\frac{3}{4}$ in. thick was not melted.

In all these cases, except No. 4, the water was pure Loch Katrine water.

In No. 1 experiment we can say in round figures that the temperature of the end of the tube was about 1000 deg.

In No. 2 experiment the temperature was over 600 deg. and under 1000 deg.; perhaps we shall not be far wrong if we put it down as about 700 deg.

In the third experiment the temperature was between 450 deg. and 600 deg.—probably nearly 600 deg., as when it was repeated with a little oil present (Experiment 4) the temperature was somewhat over 600 deg.

In the fifth experiment the temperature was probably about 500 deg.

In the sixth experiment, where the tube-plate was $\frac{15}{16}$ in. thick, the temperature must have been about 440 deg., and where it was $\frac{3}{4}$ in. thick, below that.

In all these cases the temperature of the water round the neck of the tube was 212 deg. In a boiler under a pressure of 160 lbs. the temperature of the water would be 370 deg., and the temperature of the ends of the tubes, under the conditions of the experiments above, would in each case be raised by 158 deg.

But we know that the condition of the supply of solid water round the necks of the tubes is very far from being fulfilled in an ordinary boiler—how far we cannot say, but the temperature may from that cause be very easily raised still higher.

Although the conditions under which these experiments have been made are not of a sufficiently definite nature to draw an exact conclusion from, they would indicate $\frac{3}{4}$ in. as about the limit of thickness of a tube-plate that can be used with any propriety, and this is borne out by experience.

I may mention that in a preliminary experiment with this apparatus the tube was merely driven a tight fit into the bottom of the vessel, and the vessel simply placed on the fire, so that the flame could escape round the outside as well as through the central tube.

When lifted off the fire the thick part of the bottom was

in 1873, work radical changes in construction. These rules, about coincident with the introduction of steel boiler-plate, based the allowable working pressure of steam upon the tensile strength of the material. Now, a high steam-pressure is the great desire of every boatman's heart, and at once the greatest tensile strength obtainable was demanded. Seventy thousand pounds was generally adopted, but in some few cases 80,000 pounds was attempted. The amount of carbon, however, required in such plates at that period of steel-plate development produced some very unsatisfactory results, and the further action of the supervisors requiring a reduction in area of at least 50% for plate 0.26 inch thick has brought the commercial product down to about 65,000 tensile strength.

Many reflections are cast upon the plan of boiler and furnace in use on the boats under discussion; and no doubt to the outsider, who never stood over a steam-boiler with 200 to 225 pounds pressure on it all day, the forms used seem very crude and wasteful of fuel; but the fact remains that, while many radical changes have been proposed and attempted, the result has generally been a speedy return to the accepted form.

In the first place, a furnace construction which will generate 90 or 100 pounds of steam working-pressure with the greatest fuel economy will not generate 180 to 200 pounds with the greatest fuel economy; in fact, it usually will not generate the last pressure at all. Change of form is absolute, and ordinarily that form of furnace which makes the desired result with the least manipulation gives the best economy.

The plan of boiler most in use is the externally-fired return-flue type, shell 40 inches diameter, 24 feet long; two return flues 13 inches, sometimes 14 inches, diameter; shells 0.26″ thick; flues 0.29″ or 0.3″, when made in rings 24 inches long; rivet-holes drilled, and longitudinal seams double-riveted. This boiler receives certificates from the government inspectors allowing, for 70,000 T. S., a maximum working pressure of 182 pounds, being one sixth the ultimate bursting strain of the shell; but nothing has yet been devised to prevent the operators from exceeding this limit, and 200 to 225 pounds is frequently maintained.

There is always a disposition to do a little more work, particularly with tow-boats. The numerous pier bridges and dams placed in the river in recent years incite preparation to

meet the demands in "running" them, and nothing comes nearer doing this than a "wad" of steam at the proper time. Fifteen years ago, with iron boilers of no defined tensile strength, 160 pounds was "big steam." Now, the facts are as stated.

The evaporative duty of these boilers is about seven pounds of water per pound of coal, and when compared, on a basis of the foot-pounds of work done per pound of fuel, show favorably with any water craft. The demand made upon boilers using the water of these silt-bearing streams is very heavy, and imposes conditions under which other forms, although possibly of better fuel duty, fail in points of service and steadiness.

Much indirect harm is done by a requirement of the supervising inspectors, that a water-space of at least 3 inches should be preserved between the flues and shell, and between the flues themselves. Previous to this enactment, about 1½ inches of space was the practice. The men who made these boilers had always used a 14-inch flue in a 40-inch shell, and they knew no other proportions. As a consequence, in order to comply with the new law, they raised the flues in the shell sufficiently to secure the required 3 inches of water-space, and thereby vastly diminished the steam space, as well as curtailed the surface for the elimination of the steam.

There is one other form of boiler almost as popular as the "double-flued." The shell, 42 inches diameter, contains six 8-inch flues, in two rows of three each, the one flue immediately above the other. This gives easy access to every part for cleaning and repair, and steams very well. One such boiler 18 feet long, 210 square feet heating surface, 20 square feet grate surface, is supplying two engines 10 inches diameter, 48-inch stroke, at an initial pressure of 170 pounds. The engines indicate an average of about 170 horse-power, and fuel consumption is 500 to 600 pounds per hour, or a result of 3 to 3½ pounds of coal per H. P. per hour.

Several cases of compounding have given a better result than this, but always at greater first cost, large additions in weight and cost for maintenance, and have generally been succeeded by direct high-pressure in the next boat built by the same owners.

The large increase in working pressures of late years has

demanded greater strength in the machinery and fastenings, and also in the hull construction, but the increase in weight has not been proportionate to the increased power developed, and the service has thereby been improved.

The changes in valve-gear have not been extensive. The plan shown in Fig. 11 has been introduced, and is meeting with some favor. In this valve-gear the effort has been to retain the good qualities of a " cam " movement and improve the results of its action. In the ordinary " lever " gear, four valves, two receiving and two exhaust, are employed to each engine; two engines attached to a common shaft at 90°; two cams are used to each engine—one full stroke, one cut-off. When the engines are in full gear the full-stroke cam operates four valves, raising one exhaust and one receiving valve at opposite ends of the cylinder at the same moment. This one cam does all the work in both full-gear motions of the engine, and is therefore in its neutral position when the crank is at its dead point; the cut-off is engaged after the full gear has given headway to the boat, and is used only in the forward motion. This arrangement necessarily precludes any cam position securing either an early exhaust opening or early closing of the opposite valve. A partial remedy to the consequent poor action has been found by blocking the exhaust lifters, so as to secure a somewhat earlier exhaust, but likewise a later exhaust closure; so that, with the cam in neutral position and the crank on its dead point, both exhaust-valves are partially open. When in full-gear, a slight "blow through" arises from this condition; but after the cut-off is engaged it disappears, because the opening movement of the cut-off cam is much slower than the full stroke.

Fig. 11 indicates a recent gear, employing two full-stroke cams, one for each motion, and set for the usual lead, etc.; also a cut-off cam to each engine. The drop in the lifter of receiving valves allows the lead of exhaust cam to operate the exhaust valves without affecting the receiving valve until the proper time. The cut-off cam is also advanced, and its cut-off point adjusted to meet the altered position.

In a paper read before the American Society of Mechanical Engineers by the writer of this paper, and from which some of the data herein are taken, an opinion was expressed that the improvement in the navigation of the Western waters

S.S. S. G. REED (OREGON RIVER BOAT).
175 feet long, 32 feet beam, 6 feet hold.

of the United States would be found in the adoption of composite-built boats, the frames and sides above the light-draught line being of steel, the bottom and sides, up to the light line, of wood.

Since this opinion was given in the paper named, several boats of this construction have been built, one by the writer, which has been entirely successful in general results, although open for future improvements in detail.

The mistakes, if any, have been in the direction of the use of too heavy steel for the frame construction. It has long been accepted as an axiom by Western boatmen, that a stiff boat would not be so speedy, under the same conditions, as the same boat were she limber, but the results so far obtained by composite construction explode this idea entirely ; speeds which have been obtained with the stiff construction being in every case better than with the limber boat.

Reference has been made to the fact that light construction is essential for this class of craft, and that in undertaking to develop an excessive amount of power, in proportion to the displacement or buoyancy of the boat, bad results have been obtained. For this reason the hull construction must be with a large number of dead flat frames in order to preserve buoyancy. On some of the rivers of the Pacific Slope, especially the Oregon and Willamette, boats have been constructed on much better model and easier lines than any on the waters flowing into the Gulf of Mexico.

Fig. 12 represents one of these boats, the "S. G. Reed," and gives some idea of the really fine lines found in them. This practice is possible with them through the use of timber which weighs between 25 and 30 pounds to the cubic foot, while the live-oak used for boat-building on the Ohio and Mississippi rivers and tributaries weighs between 60 and 70 pounds to the cubic foot.

The boat represented in Fig. 12 is very much stiffened by the use of fore-and-aft bulkheads through the hold, there being nine. These bulkheads are not in the way, because the load in this case is carried on the main deck; such a practice with the live-oak would make the boat entirely too deep in minimum draught. The greater first cost for composite-built boats over wooden boats is all that prevents their rapid introduction in the Ohio and Mississippi rivers, but it is to be

hoped that this will not long stand in the way of their general introduction. There can be no question that the greater first cost is now justified in the long life and diminished cost of maintenance and repairs.

Not only is steel production diminished in cost, so that angles and shapes are coming into more general use for all purposes, and this increased output further assists to lessen the cost, but live-oak timber is becoming less accessible, and is increasing in first cost.

It would seem that these causes ought soon to produce a result which would equalize the present cheapness of wood boats over composite boats, at no distant date.

The work of the United States Government in the improvement of these waters (the Ohio and Mississippi rivers and their tributaries) has been vastly beneficial to navigation in every respect. This is particularly true of the Ohio River, where a system of movable dams is now being inaugurated. One of these dams has been in operation a few miles below Pittsburg for several years, and has given unqualified satisfaction, with the exception of a few details in original construction, which have since been remedied. The second of these dams has now been authorized by Congress, and must necessarily lead finally to a complete system throughout the river. Such facilities will give a new impetus to the navigation of these waters, and an immense demand for increased tonnage will be the result. Through these means will no doubt come an intelligent improvement in respect to hull and machinery construction, with closer attention to fuel economy. The evolution is slow, but it is being evolved, and the time is not far distant when radical changes may be hoped for.

Since the preparation of this paper, the writer is indebted to Capt. Ed. J. Howard, proprietor of Howard's Ship Yard at Jeffersonville, Ind., opposite Louisville, Ky., on the Ohio River, for a photograph of the steamer "City of Hickman," and also for a photograph, made from a woodcut in Capt. Howard's posssession, of the steamboat "Tecumseh." Cuts of these boats are hereto appended, as indicating the change in dimension and appearance between the two extremes of time, 1826 and 1892. The "Tecumseh" was built at Cincinnati, Ohio, in 1826; was a single-engine boat, and had the

sleeping accommodations for passengers in the hold. She was a celebrated boat at the time, because of the fact that she made the run from New Orleans to Louisville in something over eight days. The "City of Hickman" is the property of the Anchor Line, operating between St. Louis and New Orleans, and is a fine illustration of the excellent boats used in that service at the present time.

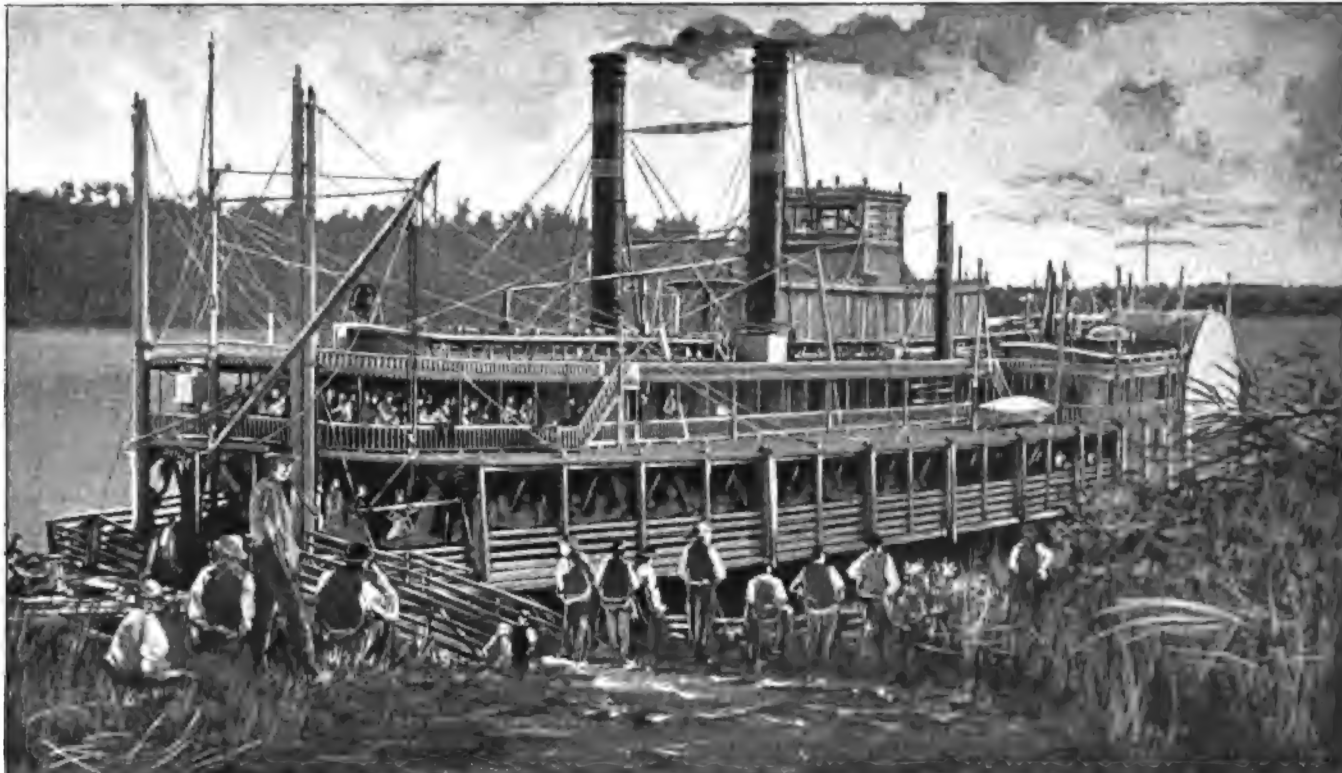
DISCUSSION ON THE CONSTRUCTION OF STEAMBOATS NAVIGATING THE WESTERN WATERS OF THE UNITED STATES.

PROF. JAMES E. DENTON:—As a possibly interesting supplement to Mr. Sweeny's valuable paper, I venture to add the following results of efficiency tests of the propelling machinery of one of the peculiar styles of steamboats to whose discussion the paper is devoted.

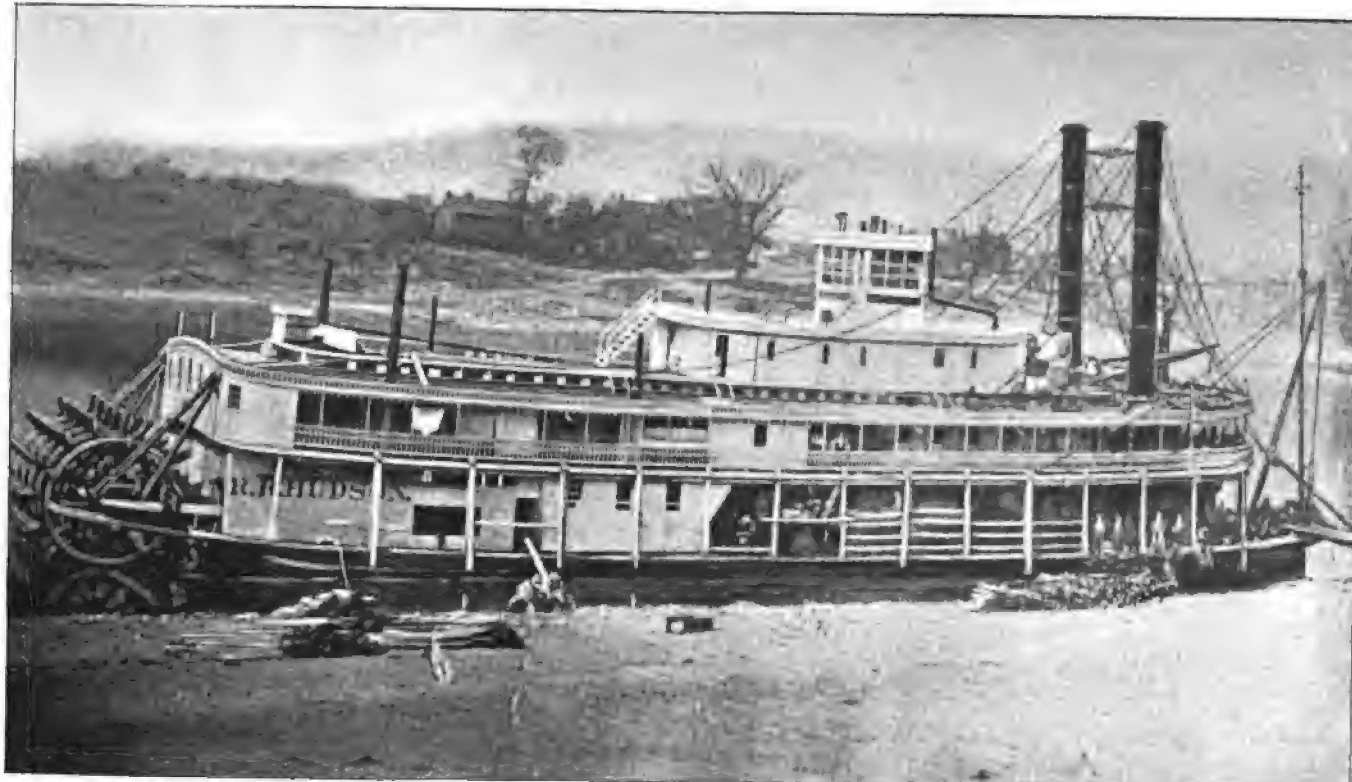
The data were secured by Messrs. Wm. Whigham and C. V. Kerr, graduates of the Class of '88 at the Stevens Institute, during some careful tests conducted by them on a voyage between Pittsburg, Pa., and the mouth of the Red River, La.

DIMENSIONS TOWBOAT "O'NEIL."

Length of hull, feet	201
Depth of hold, "	8
Width of top of hull, inside guards, feet	38
Diameter of wheel, feet	28
Length " " "	28
Material " "	wood.
Number " " buckets	17
Width " " " feet	3
Dip " " " " loaded	3
Number of cylinders, main engine	2
Diameter " " " " inches	24.5
Stroke " " " " feet	12
Clearance " " " " per cent of piston-displacement	8
Number of boilers	6
Diameter " " inches	47
Length " " feet	28
Number of flues in each boiler	6
Diameter of flues, inches	10
Heating surface, square feet, total	3979
Grate-surface " " "	138
Ratio	28.8



S.S. FLEETWOOD.



S.S. R. R. HUDSON, 1865.

ness, it would be apt to give way there, and to show it before bulging out between the circumferential laps.

MR. McFARLAND:—I only want to speak on one thing that my friend Mr. Kafer mentioned, and that is in regard to the factor of safety, as I was interested in some parts of the Frye bill. That very question as to what should be the factor of safety came up, and after giving the matter a great deal of careful attention and thought, we advised that the factor of safety should be made the same as recommended by the British Board of Trade, namely 5. Now the very fact came to our notice that Mr. Kafer has called attention to, that, owing to the Supervising Inspector's rules, although there is nominally a factor of safety of 6, by means of the allowance for double riveting it is brought down to 3½ and sometimes less. The question then naturally arises, "If it is absolutely necessary to have a factor of safety of 5, why do not these other boilers blow up with factors of safety of only 3?"

Well, I happen to be located in Washington, where we do not have enough steamers to let me investigate the matter personally; but, very curiously, in the first two cases that did come under my notice immediately after the publication of the Frye bill, I found that the boilers were run with only about one half to two thirds the working pressure allowed by the Supervising Inspector's certificate. They had nominally a factor of safety of 3½, but they really had a factor of safety of 7 with half the working pressure.

I asked a friend of mine who was in New York to take every opportunity he had when on board any steamer to look up that question and to find how near to the working pressure allowed by certificate to the vessel the pressure actually carried was. That was the partial solution of the question that occurred to me; that, although the factor of safety would be so low if they carried the working pressure allowed by certificate, as a matter of fact they do not carry so much pressure, and so were really running with a factor of safety of 5 to 7.

COMMODORE LORING:—Where was that?

MR. McFARLAND:—On two boats in New York Harbor. I could not say how far this state of affairs is true generally, but I say, curiously enough, in the first two cases that I investigated, taken at random, both of them happened to be running below the allowable working pressure.

Without wishing to bring up a discussion on the strength of materials or factors of safety, it seems to me that it is worth while discussing, just for a moment, whether it is safe to run with a factor of safety lower than 5. As I understand it, in bridge construction,

and in almost all other metal constructions, where there is nothing else than an absolutely quiescent load, a factor of safety of 5 is considered about as low as is desirable. Of course it is needless to say in such an assemblage as this, that a factor of safety of 5 does not mean that our structure is five times as strong as necessary. It simply shows that one fifth of the ultimate tensile strength is the safe working strength; and if the gentlemen of great experience in this congress can say from their experience that a factor of safety of $3\frac{1}{2}$ is all that is necessary, our meeting will not have been in vain, if we can establish that one point thoroughly.

MR. FRANK B. KING:—It does not seem to me that we approach this factor of safety logically at all. At the present time we are building boilers with shells as thick as an inch and nine sixteenths and as thin as a quarter inch. Corrosion plays such an important part in the matter that the only sensible way of getting at it is to have a sliding-scale of factors of safety, adapted to the varying thickness.

COMMODORE LORING:—It is the practice of inspectors and not the rules that are at fault. The rules provide that the inspector may demand that the plate be drilled: that is what he bases his calculations on.

MR. OLDHAM:—I think the British Board of Trade and the British Admiralty have thrown the factor of safety away altogether. And if our builders take great care in the construction of the boilers, make them in the most careful manner, carefully riveted and examined, I think there is very little necessity for the factor as a factor. As I understand it, they calculate the strength of the boiler, and then they test it, and take $\frac{4}{5}$ of the test-pressure as the working pressure. I think you will find there is not a factor of 3.

MR. MCFARLAND:—There is a factor of over 4, because they purposely keep the test-pressure inside the elastic limit, and that is about fifty per cent of the ultimate strength.

MR. JAMES HOWDEN:—I have listened with much interest to the lengthened discussion of these two papers, but I am afraid there is now not much time left for further remarks.

While listening to the reading of the first part of Mr. Stratton's paper regarding the strange anomalies possible in boiler-construction under the Government inspection, I began to feel very apprehensive as to one's safety in travelling in this country, but I became somewhat reassured towards the end of his remarks when I found that the engineers of the country and the registration societies came in on the other side to keep matters right.

I have had the opportunity of examining some boilers being

made over here, and they appeared to me to be of such scantling and construction as would pass our Board of Trade rules and inspection, so that, whatever the Government inspectors may do, the engineers who build the boilers and are responsible for good workmanship and proportions, as well as the registration societies, appear to balance off what is defective in the anomalies connected with the Government inspection. I am not quite sure, but probably I am the only manufacturing engineer out of the country who has made boilers for steamers built here and running under the American flag. These boilers, built in Scotland, had consequently to pass the American Government inspection. I made these boilers, so far as I remember, to our Board of Trade rules. The plates were made in America and were tested by the Government inspectors here before shipment. The drawings of the boilers which I sent to this country were all approved and passed, so that I have nothing myself to complain of in regard to your Government inspection.

There is just one part of Mr. Foley's paper which I will refer to, though it contains much interesting matter. It is that part dealing with the strength of furnaces where he gives the British Board of Trade rules, American rules, Lloyd's, and others for finding the thicknesses allowed for given sizes of furnaces of different forms and construction. Now in the getting up of all these formulæ there is one element which has not been taken into consideration. They have all been based on the power of the respective furnaces to resist collapse under cold-water pressure. The new registration society which has been recently formed, the British Corporation Registry, which has its headquarters in Glasgow, is the only one that has taken into account in its formulæ for strength of boiler furnaces the conditions under which the furnaces have to work. This has been chiefly owing to my suggestion, as I happen to be a member of the committee of that Registry.

In the Board of Trade rules, Lloyd's and other registries, the tensile strength of the steel plates used in the furnaces largely affects the formulæ, Lloyd's especially giving a high allowance for increased tensile strength of the steel to certain furnaces. Now, when we come to consider the conditions under which a furnace-flue collapses, we find the effect of the high tensile strength under the cold-water test has little or nothing to do with it. The furnace is then hot, heated to softness, so that all the differences arising from more or less tensile strength of the furnace-plates to resist collapse under cold-water pressure disappears.

In the case of the corrugated furnace, where there is, as it were,

a good deal of spare cloth in the extra plating of the corrugations, and also in Morison's furnace to a less extent, though they show a very high resistance to collapse under cold water, when a part becomes heated to softness in working they begin to collapse, and all their high strength, as shown in these tests, disappears. If the partial heating extends much, down the furnace comes, down to the furnace-doors, which I have known in dozens of cases with corrugated furnaces. What I say, therefore, is, that these rules are founded on the mistake of omitting to take into consideration the actual conditions under which these furnaces have to work.

The Adamson ring-furnace meets the actual condition of furnace working better than any form I know. I have used these rings exclusively for twenty-three years in marine boilers. When high pressures came in I had great difficulty with the Board of Trade and Lloyd's in getting a proper formula for this form of furnace, no matter how close I brought the rings together. They would only look upon it as a plain furnace, or at least give it the same coefficient as a furnace with one ring only. I had then to make a small boiler-shell with a furnace in it, which was tested to destruction by the Board of Trade, who then gave a certain formula. Lloyd's followed some time after. I was then, I believe, the only one in Great Britain who constructed furnaces for high-pressure boilers with Adamson rings. In some cases I brought the rings as close as 17 inches apart. In the furnace I made for the Board of Trade tests the rings were 23 inches apart. What I believe is, that furnaces with Adamson rings, properly made, and with the rings properly pitched for the diameter and pressure to be used, are the safest by far of all forms of furnaces used for high-pressure boilers. Should there be, for example, incrustation on the top of a furnace of this kind so great as to cause a heating of the plating sufficient to soften it, the plate may be dimpled or bulged inwards between the rings, but it will not collapse. This is owing to these immensely strong rings being in the water on edge, where they cannot be heated up. They therefore keep the furnaces perfectly circular, and the worst that happens, with an amount of heating sufficient to collapse any other form of furnace, is only a more or less bulging of the plain plate between the rings, which may be 18 inches or more apart. These bulgings generally take place so gradually that they give you warning, as you can see them coming.

In the case of a new steamer which I had fitted some years ago with boilers having these rings, she was steamed home from Singapore with salt water in the boilers, and part of the way, at least,

carrying 160 lbs. pressure. This was owing to some carelessness of the engineer, or mishap that occurred, so that he was feeding the boilers with salt water all the way. On arrival at Liverpool almost every plate between the rings over the fires in her six furnaces was more or less bulged in, but on opening up and examining the boiler this was no cause for wonder, for the boiler was nearly filled with salt. Two thirds of the tubes had to be removed in order to clear the salt out from them and the remaining third. You can understand what a severe test that was upon these furnaces. They were 3 ft. 3 in. in diameter, and had rings 23 inches apart, yet the bulges were all heated and set up in place within a week, and the boilers continue to run with the furnaces as good as ever. Now I believe that no other form of furnace could have stood such an extreme test as these furnaces did without collapsing. Corrugated and other forms of furnaces, however good they are in many respects, are not to be compared for safety with the Adamson ring-furnace properly made. It must, however, be properly made, solid welded and flanged, and annealed at two different stages in construction. The flanges also must be perfectly drilled and riveted, so that the rings do not need to be afterwards touched. The British Corporation Registry have recognized the fact that the Adamson ring-furnace so made is of a superior character, and have given it the same formula as they have given the corrugated, the ribbed, and the suspension furnace, which, however, by no means overrates its merits.

MR. COLE:—It occurred to me over twenty years ago that a cold hydrostatic test might be an injury, instead of a test of the safety of a boiler, and this led me to think of a better method. My idea is, that the best plan is to fill the boiler completely and then obtain the pressure by a fire in the furnace, just as when it is in use. Watch the pressure-gauge, and as soon as the test-pressure is reached release all pressure from the boiler. I submitted this to Secretary Sherman of the Treasury Department, who turned it over to the Board of Supervising Inspectors, and I presume they have it pigeon-holed now. I would be glad to have the views of gentlemen here as to the merits of my plan.

MR. JOHN C. KAFER:—That has been done very many times, and in testing boilers we would do that—build the fire in the furnaces, heat the water very hot, and put the additional pressure on, probably hydraulic pressure, when the boiler is very hot, and also without the hydraulic pressure—generally do it in both cases.

MR. E. E. ROBERTS:—I have made that test myself, years ago, and always found that a great difficulty in regard to it was that a

very few small leaks would let as much water out of the boiler as would counterbalance the expansion of the heat.

I came here for information. I can find no adequate rule in the regulations of the United States inspectors of steamers which will give me information in regard to the bracing of the heads of steam-drums. We build a water-tube boiler to carry 250 lbs. of steam, and we have been accustomed to using braces from head to head which were one square inch in area of cross-section, and the question in my mind has been, how much pressure should be supported by them—that is, how much of the area should be supported by the braces and how much by the rivets? What proportion of area should be allotted to each? I have never been able to get any precise information on that point and have been accustomed to placing our braces 4½ inches between centres and 6¾ inches from the shell. In other words, we allowed the rivets to support the same as the braces,—the same as the external circle of braces.

On May 13, 1893, an amendment was made to the rules of the Supervising Inspectors which required water-tube boilers to withstand a test of double the pressure which it is intended to carry, instead of 1½ times, which has been generally applied to these boilers. I think that is an injustice to us, because almost all water-tube boilers are made up of one or more shells, of some kind, and tubes, which is exactly the same construction as the shell boiler, only in a different way—in other words, that the test is on the shell as well as on the tubes; and I do not see why we should be compelled to withstand double the working pressure, instead of 1½ times the pressure as in the case of so-called "shell" boilers.

COL. E. D. MEIER:—In regard to the factor of safety, as understood by the Inspectors of the Treasury Department, I would like to say a word, as I had occasion to figure over the rules that they applied to passenger steamers on the Mississippi and Ohio rivers,—in fact on any steamer in the Mississippi Valley. I found that the practice in regard to riveting which prevails to a large extent in the boilers of ships for that river was that you could use 18,600 lbs. on sections of metal which would stand perhaps 65,000 lbs. Now there was a factor of safety of about 3½, and there is not any doubt in my mind that these river steamers carry up to the full limit; it is a great question whether they do not exceed it, but they seldom carry below. I think the main difficulty in the Treasury rules lies in the fact that nothing is said about the method of riveting.

In regard to the elastic limit, as mentioned by Mr. Kafer, I have always believed that that was the only true value upon which to base your factor of safety, because if a factor of safety has any

meaning at all, it is to show how much safety you have,—if you have not any safety beyond the elastic limit. The difficulty with the ordinary run of inspectors, such as have to be appointed by the Treasury Department, is that you will not get the necessary skill to determine the factors of safety accurately. I think that the whole difficulty ought to be remedied by an entirely different method of testing. I believe the method of testing where the boiler is built and the testing done on small and inferior machines is wrong. I think the testing should be done at those points where the steel is manufactured. That would reduce it to very few machines and a very few inspectors who may be more skilful in testing.

MR. J. H. HARRIS:—I have had a great deal of practical experience as an engineer of steamboats on the Mississippi, and one instance comes to my mind to show the absolute unreliability of the usual hydrostatic test. We had our boilers tested while at St. Louis to 225 lbs. Just before reaching Memphis (400 miles away) a bad leak showed in one of the legs to the mud-drum. In repairing it, we found the metal as thin as a knife-blade. It could not possibly have been corroded to an appreciable extent in the 48 hours that had elapsed, and, by all the rules of calculation, it ought not to have withstood anything like the test-pressure that it really did.

With regard to carrying steam below the limit allowed by the certificate, as mentioned by Mr. McFarland, I am sure that he can never have travelled on the Mississippi steamboats. I knew personally of boilers that were in use for twenty years, thirty-six inches in diameter and two tenths of an inch thick. I don't believe they ever turned a wheel under 165 lbs. pressure, and I have frequently carried 200 lbs. on them.

In view of these and similar facts, I am rather inclined to favor a reduction of the factor of safety. We have very few explosions here in the West and the loss of life is very small. As one speaker has expressed it, I believe in taking some risk. I do not believe in having a high factor of safety if it is not really necessary.

MR. SWEENEY:—Mr. McFarland's story of the boat that was operated on less than the allowable pressure could certainly have only been the case because she did not have the capacity to generate the pressure. If there is any other reason for it, I would like to know what it was. A factor of safety by law is one thing, an actual factor of safety under which boilers are operated is an entirely different thing. On the Western rivers the steam pressures allowed by law are always exceeded, and they are exceeded to a percentage in regard to which a statement might be disbelieved unless it was witnessed. Many of the boats that are allowed a working pressure

of 180 pounds of steam, at times go to 240 and 250 pounds. The actual factor of safety under which those boilers are working is much less than the law establishes. Now, if the law reduces the factor, that will not stop over-pressures, and the result will be that the actual factor will be away under what was intended. That is the risk about reducing the factor.

One matter in this paper that I have not heard discussed is whether a percentage of hydrostatic test double the allowable working pressure is preferable to what I notice under some of the rules —50 per cent of the allowable pressure added.

In the matter of the drums which Mr. Harris mentioned, I have seen cases of corrosion discovered after a hydrostatic test had been applied to the boilers, where I have run an ordinary knife-blade through the drum, alongside the legs. That is the place where corrosion is usually found in our boats, because the accumulation of soot and ashes on top of the drums, which are not properly taken care of and cleaned, causes this corrosion. I have seen several cases where you could put a pocket-knife-blade through the drum, and still that drum had stood a hydrostatic test as required by law immediately before.

MR. A. H. RAYNAL:—The subject is of such vast importance to all of us that I would like to add a few words. In regard to Mr. McFarland's statement that occasionally the boiler-pressures on steam-boats are not up to the limit allowed by law, I can state from experience in New York Harbor that such is the case. My business has been very largely to furnish propeller-wheels for tug-boats. I would send a blank to be filled out with the full data of the boats, and in nine cases out of ten there was a difference of about ten pounds,—say, 90 pounds of pressure allowed, 80 pounds used,—and on most of the tug-boats on which I have been it is so. It is a fact that in a great many cases the pressures carried are lower than those allowed by law.

In regard to the factor of safety, I think from large experience myself that it could be lowered to 4, but I hope that in the future the elastic limit will be used and not the ultimate strength. Mr. Howden has remarked that, as to furnaces, his experience has been that the Adamson furnace was the best and the one that gave satisfaction throughout in preference to all others. On this side of the water we have been using almost exclusively the corrugated furnace, and to my knowledge I have not yet heard of a single case in which there has been a giving way or dissatisfaction, and if I am in the wrong I would like to be corrected.

MR. GEO. W. DICKIE:—I would like to ask a question in regard

to two statements that have been made here in this discussion: one that it is quite a common thing in a boat certified to carry 150 pounds of steam to carry 200; the other that it was quite common under a certificate for 150 pounds to carry as high as 240. Now the law states that the safety-valve shall be locked at the pressure which the law allows. How is it possible that a boat whose safety-valves are locked at 150 pounds steam can carry 240?

MR. SWEENEY:—To my knowledge there is no law requiring lock-up safety-valves on the boilers of Western river steamboats.

MR. DICKIE:—I have only been within sight of Western waters for a few days, but if the law locks the safety-valves, why should it make any difference whether the vessel is in Western waters or any other waters as to blowing off of steam when it reaches the pressure at which the valve is locked?

MR. KAFER:—A man disobeys the law when he tampers with the valve.

MR. SWEENEY:—One way is to tie down the safety-valve. I have known cases where a washer was used on some of the valves below the guide, put inside of the boiler, so that it could be pulled off. When the engineers thought they would be caught at it, they would get on the boilers, raise the lever, push the washer off the end, and it would drop in the boiler.

MR. DICKIE:—This reminds me of a little story in connection with the boiler of a tow-boat which we had completed just as the law went into effect requiring that each boiler should have a spring-loaded safety-valve, independent of the weight and lever-loaded valve, which at that time satisfied the requirements of the law. The inspector required that this boiler should be immediately fitted with a spring-loaded safety-valve to comply with the law just issued. The boat was to go to sea next morning, and the safety-valve was procured and sent down to the engineer, he agreeing to have it put on the boiler that night. Next morning the boat went to sea, apparently all right. Two years after this the engineer was discharged from the boat. He came to me very uneasy about something. "Do you know," said he, "that I never cut a hole in the boiler where that safety-valve was put on, and I would like to have it rectified."

In regard to corrugated furnaces as compared with those fitted with the Adamson ring. One of the United States ships, the "Charleston," is fitted with the Adamson ring, and Prof. Hollis, who was for some time on that ship, might be able to tell us whether there was any trouble with any of her furnaces, any difficulty in cleaning, or anything of that kind that might be charged to the

presence of the Adamson ring on the outside of the furnace. This question of the strength of furnaces is very important.

In regard to the statement made that there were no cases of corrugated furnaces failing. I may state there is no end of trouble with furnaces with us, and corrugated furnaces are no exception to the rule. One of our new ships, the "Peru," has had several of her furnaces get out of shape owing to the presence of grease in the boilers. The China steamers running between British Columbia and China have had a good deal of trouble with the furnaces getting of of shape, and quite a number of them have had to be replaced. There is the same difficulty with furnaces of all descriptions, and I am prepared to indorse Mr. Howden, it being my opinion of the Adamson ring that, standing up as it does in the water, the main body of the metal is kept cool and maintains its shape and that of the furnace in its immediate vicinity, no matter what happens.

MR. J. F. MILTON:—The subject which Mr. Foley has undertaken to review is one of great importance not only to engineers and shipbuilders, but also to shipowners; the paper is one, therefore, which is likely to excite great interest. As, however, it appears to me that Mr. Foley has not dealt satisfactorily with the subject, and as some of his remarks appear to be inconsistent with others, I venture to offer a few criticisms upon his paper. I shall deal only with a few points; but while not making any remarks upon other parts of his paper, it must be understood that passing them over does not imply approval of the views enunciated. The paper is too long, however, to criticise in every detail.

At the outset it is to be remarked that Mr. Foley nowhere draws attention to the fundámental differences between the objects which should be aimed at by the rules of government departments on the one hand and those of registration societies on the other, nor does he notice the great difference between their incidence. Instead, therefore, of comparing how the various rules fulfil the conditions which have called them forth, he compares them with one another as if they aimed at the same thing, and afterwards compares them with his own ideal, which in itself, in some respects, does not appear to be a fixed quantity.

The rules of the government departments criticised by Mr. Foley are the statutes of the United States which are *enforced* in the case of all boilers of United States vessels, and those of the British Board of Trade which are *compulsory* in the case of boilers of British passenger steamers. There is no compulsion whatever for the boilers of any vessel to be built under the rules of any reg-

ment or society, as compliance is in all cases purely voluntary. The use of the word "enforced" in the heading of the paper is therefore misleading. It is not necessary to say more as to the incidence of the rules than that while some are compulsory in the cases to which they apply, others are always purely voluntary.

Next, as to the object aimed at by the various rules. In all cases the object of the rules is primarily to provide for the "safety" of the boilers. All the rules, therefore, are framed to fix the working pressure to be allowed, and all therefore are presumably intended to be based upon the actual strength of the boilers. In the case of the registration societies it must be borne in mind that vessels are in general classed for extended periods, in fact so long as they are found by periodical surveys to have been kept up in good condition. It is therefore necessary that the rules for the *original* construction of their boilers, like those for the original construction of the vessel, should provide at the outset sufficient margin to insure continued efficiency for long periods when subjected to the reasonable amount of wear and tear which extended experience shows to be inevitable in all classes of boilers.

In the case of the enforced rules of government departments, however, this does not hold to anything like the same extent. It is not the business of any government to take such care of shipowners' interests as to provide for the long-distant future, but only to take such measures as will insure safety during the limited time which must elapse before the boilers to which the rules apply come again under survey. This period is rarely, if ever, more than twelve months.

Mr. Foley has not only lost sight of this great distinction between the two cases, but he expressly states, over and over again, that he objects to any provision being made in the rules for corrosion taking place, although he admits that some parts of boilers are "peculiarly liable to corrosion," and also states that "an allowance for corrosion cannot be objected to from an owner's or inspector's point of view, they being the best judges of the circumstances under which the boiler is going to work." It is unfortunate that to Mr. Foley's experience as a constructor of machinery and boilers there has not been added that of the frequent examination of boilers of varying ages, different designs, and which have been subjected for longer or shorter periods to all kinds of treatment incidental to years of service, frequent changes of engineers, etc. He would then probably have held very different views as to the desirability or necessity of providing a margin for wear and tear in the original construction of the boiler.

Mr. Foley throughout seems to lean to the Board of Trade rules, and wonders why they "have not been generally adopted by all the other bodies, with such changes in constants as might, after careful investigation, have been thought safe and prudent." As a matter of fact this is exactly what the other bodies have done, and what they could not help doing. The "pioneer" rules, as Mr. Foley calls them, were based on the principles which govern the strength of structures, and the "constants," as he calls the various coefficients, have been in some cases varied by the Board of Trade as well as by the other bodies, presumably because the variations have been thought to be "safe and prudent." To see that this is so we need only to point out that the factor of safety employed in the Board of Trade rules for boiler-shells was originally 6. It was then reduced to 5, and has lately been again reduced to $4\frac{1}{2}$. The great differences between the rules of the various bodies are as to what values it is "safe and prudent" to give to the so-called "constants," and whether it is not advisable to omit some of them altogether.

In comparing the various rules, we may at once dismiss the requirements of good and accurate workmanship, which are equally implied in all the rules, as all surveyors, whether they be of government departments or registration societies, are supposed to see that the workmanship is good; and although the Board of Trade, in the case of boiler shells, provides for approving, although at a reduced pressure, of work that is not good, yet this rule can scarcely ever be applied, as owners would not accept work to which attention was prominently drawn by a reduction of working pressure. It is strange, however, to read, in Mr. Foley's review, of so many hints of inferior workmanship as are implied by the words "considerable abuse" and "difficulty of closing," "sudden and mysterious flaws," on page 12; "abuse to which the material is subject," on page 33; "usage of the boiler-shop," and "liability to cracking," on page 34; "drawing up," and "possibility of cracking," on page 35. These certainly lead to the inference that the standard of workmanship is not so high in Italy as in Great Britain.

When we come to the question of suitable materials for the different parts of the boiler, we find Mr. Foley holds very peculiar views, which, moreover, are not consistent throughout the review. In recording the requirements of the rules he is criticising, also, he is not accurate, for at least those attributed to Lloyd's on page 24 are nowhere to be found in the rules of Lloyd's Register.

Mr. Foley starts on page 11 with the proposition that "we require a material as strong as we can reasonably get it, provided it

has certain other very necessary qualifications." What these very necessary qualifications are he does not state, unless he implies by the quotations above recorded ability to withstand bad workmanship and improper treatment. On page 13 he says, "The actual strength seems to me of little consequence within considerable limits;" and again on page 6 he says: "It would appear that the strength within a few tons per square inch has very little to do with the strength of boilers." In face of these statements of his opinions he, throughout the review, recommends various qualities of steel for different parts of boilers, the strengths varying by such small quantities in some cases as half a ton per square inch, as will be seen from the table given below. All the strengths recommended, however, are below that of which good material can be "reasonably" got.

It must be remembered that the material under consideration is *steel*, not *iron*, and that steel boiler-plates have to be made under ordinary commercial conditions, and that, although by varying the proportions of carbon and manganese, steel can be produced with any desired strength within the range of from about 23 to 40 tons per square inch, steel-makers have not yet arrived at such precision in their work as to be able to dispense with some margin in the strength. They find, indeed, that in order to produce steel with commercial success a range of two tons above and two tons below any specified strength is necessary. Mr. Foley's suggestions, however, imply far more skill and precision than steel-makers can lay claim to.

The following table shows the proposals he makes:

Purpose Intended.	Strength, Tons per Square Inch.		Minimum Elongation in 8 in.	Radius for Inner Curve of Bend Test after Tempering.
	Minimum.	Maximum.		
Rivets	22.5	None stated.	26 per cent.	To be bent close
Flat plates	23	"	25 "	One thickness
Furnaces	24	"	26 "	"
Stays	24	"	25 "	To be bent close
	24	"	20 "	One thickness
Shell-plates	25	"	25 "	"

Steel-makers cannot and do not pretend to discriminate between such materials as will give in one case 25 per cent and in another 26 per cent elongation with the same tensile strength, and even Mr. Foley on page 43 gives for stay steel the two different requirements of 20 per cent and 25 per cent elongation.

I think a protest should be made on behalf of steel-makers against such imputations on the quality of the steel they make, as the word "brittle" on page 13, and the remarks as to an engineer being "shot while calking a boiler under steam" when refer-

ring to material which has in all cases a minimum elongation of 20 per cent in 8 inches. If it becomes brittle, it is not the fault of the steel, but of the manipulation and treatment it undergoes. Mr. Foley has evidently meant high and low *tensile strength* instead of high and low *quality* on pages 13, 25, 34, and 35.

Leaving the question of material, let us refer to the rules relating to details of construction. With the exception of the United States Statutes, all the rules assume that the strength of the boiler-shell depends directly upon that of the longitudinal seams, and practically all calculate the strength of this joint in the same way, from the actual diameters and pitch of the rivets. On this portion of all the rules therefore there need be no comment. In addition to varying the pressure in accordance with the strength of the joint, the Board of Trade have no less than 25 modifications of the pressure provided for in their rules, in accordance with difference of design or methods of workmanship, some of which can have no influence whatever on the strength of the boiler. For instance, according as the holes in either or both of the longitudinal and circumferential seams are drilled in place or out of place, so the pressure is varied; although in all cases it is stipulated that the holes are to be drilled after the plates are bent, and that they are all to be fair and good. What difference in the strength can exist in these cases? Yet Mr. Foley says of these and similar regulations: "the principle" . . . "is correct," on page 6; and the list is "admirably drawn out," on page 22. However, his remarks on this point are somewhat qualified on page 10, where he says: "Referring again to the Board of Trade additions, it may "well be asked why in all cases they should be cumulative." In my opinion no modification of the pressure on account of different methods of construction can be justified, unless these methods have a direct bearing upon the actual strength of the boiler.

Consider now the rules for furnaces. Mr. Foley is well aware that all rules for long plain furnaces must, in the nature of things, be approximate; but in the one feature in which the Board of Trade rule differs from the others he appeals to some six experiments, the particulars of which he does not give; and he states that their results, as measured by the Board of Trade rule, give a factor of safety ranging from 4.4 to 6.2. This is a difference of over 40 per cent, yet he calmly remarks: "therefore, . . . within the limits prescribed, the Board of Trade formula may be accepted as suitable for our requirements."

Turning now to the rules for flat surfaces. He says, page 31, "The Board of Trade rules for flat surfaces, being based on actual

experiments, are especially worthy of respect." Now the Board's rules differ in principle from those of the other rules criticised in their assuming that the strength of plates to resist buckling varies directly as the square of $\frac{1}{16}$ of an inch more than the thickness, and inversely as the surface supported minus 6 square inches, which are certainly not the results which would be expected from first principles; whereas the other rules assume the strength to vary practically as the square of the thickness and inversely as the surface supported. No details, however, are given of the experiments upon which the Board's rules are stated to be based. These rules were framed many years ago, when the number of experiments available were very few, and it is worthy of remark that Mr. Foley states that. The Chief Surveyor of the Board of Trade himself admits that "a simple rule such as the Board adopted must necessarily be incorrect outside a very limited range." As a matter of fact, within the range usually adopted there is very little difference in the application of any of the rules, but certainly if they are strained to meet the cases of extreme proportions it is not the Board's rule which would give the least unsatisfactory result. On page 31, referring to these rules, Mr. Foley says that "the jumping of the constants to new values is objectionable in the case of Lloyd's rules." As a matter of fact, the Board's own rules which he says "are especially worthy of respect" have no fewer than eight so-called constants.

On page 47 Mr. Foley gives examples of the Board of Trade rules and Lloyd's rules for tube-plates, and states that by the former the crushing stress is limited to 10,000 lbs. per square inch and also to 20,000 lbs. per square inch, while Lloyd's allow 25,600 lbs. per square inch. These last two figures are evidently slips, as by Lloyd's rules the stress is limited to 12,800 lbs. per square inch, and the first figures are correct for the Board's rules. However, commenting on the difference between these rules, Mr. Foley, who apparently objects to thick tube-plates, states that he would prefer the Board's rules for thick plates and Lloyd's for thin ones. The result of this would be to make the thick plates still thicker.

It would take up too much time to further criticise Mr. Foley's review, which, exclusive of voluminous appendixes, extends over 50 pages of print, but I hope I have shown that all his conclusions are not necessarily to be received as correct ones, and that in most of the cases in which he pronounces against any generally received rules, there are many arguments on the other side.

MR. NELSON FOLEY (reply in writing after the meeting):—Mr. Sweeney's remarks appear not to require a reply. I may say, how-

ever, that his account of how one of the furnace rules came into existence is interesting.

Replying to Mr. Kafer:—I should not object to a factor of safety of 4 provided it was assured that the elastic limit of the joints was not overstepped during hydraulic test, but I cannot agree with him that it should be fixed according to the rate of death per million caused by the failure of boiler-shells.

I quite agree that standard sizes are most essential for test-bars. Regarding the elastic limit being used as a basis for the calculations, a careful perusal of the review will show that practically I agree with him; the older system is, however, now so rooted that it would be difficult to change it; the change, although desirable, is, of course, not absolutely necessary provided we know approximately the ratio between the ultimate and elastic strengths. I should also like to point out that it is the elastic limit of the joints which should concern us most and which introduces a complication requiring some investigation.

I am quite prepared to find that many besides Mr. Kafer cannot accept a theory which embraces the length as a factor in determining the strength of a cylindrical shell with ends, to resist bursting. I would ask Mr. Kafer why the length is such an important factor in all furnaces. If he admits that it is, surely it is not inconceivable that it should form an important factor in the computation of the strength of cylindrical vessels subjected to internal pressure.

Replying to Mr. Howden, I may say that I quite agree with him in all he says.

Replying to Mr. Milton:—I am pleased that he has pointed out that, in his opinion, the rules of registration societies should not be compared to those of governments. I should have liked him, however, to show more clearly why, as we outsiders will, I fear, continue to compare them. I understand that three years is the longest period Lloyd's allow a vessel to remain without survey; vessels under government certificates must often be in commission for periods as long. Independent of this, it is quite as important to those concerned that the boilers of war vessels and passenger vessels with government certificates should last as long as those of vessels classed with registration societies, and pretty much the same desirability must exist for maintaining the working pressure without reduction in the former case as in the latter. Regarding the word "enforced," which Mr. Milton objects to when applied to registration societies: if a vessel is to be classed in one of these

once the stern of the boat leaves the shore—seems to pick it up and lift it away from the shore. I have seen these boats back up against the current where their bows were stuck on the bank until they would be at right angles to the shore before they would pull away from the shore.

No matter how hard the wind was blowing, our stern-wheel boats could get out and twist around and be gone before lake boats would be ready to start. I should like to have one of these boats working from Van Buren Street to the Fair. The experience we have had in the St. John's River, Lake Monroe, and Lake George, in Florida, has been that our boats fitted that service better than sound boats or that class of boats; they have been speedier, and would get around through the crooked part of St. John's River without any trouble, where you could jump off from the boat at either end.

Mr. Geo. W. Dickie:—There is another question. In the boats we have been discussing, it appears to be the universal practice to use the cam for the cut-off. In the stern-wheel boats on the Pacific coast the cam is very little used, and the cut-off is effected by a wedge working on top of the valve-lever. The valve is operated by the simple eccentric, and another eccentric is introduced to work these sliding wedges. Is that in use on the rivers here? What is the practice in cams?

Mr. Sweeney:—There are perhaps a dozen different devices, giving very variable expansions. The California cut-off has been used. Most of the plans for variable cut-off have the objection that the mechanism frequently fails to work when the engines are reversed; and I know of two cases where they were bodily ejected from a boat, because, landing alongside a wharf-boat, the machinery failed to back and the wharf-boat was sunk. Now the result of using automatic cut-offs on these rivers has been simply this,—that we have got down to a place where we found the boat would make steam. Boats on the river are useless unless they make steam. They want plenty of pressure all the time, and where a variable cut-off has been used, in almost every instance it has been regulated to cut-off at a point where the boilers would generate steam properly, that is, plenty of pressure, and there it has been left. That is why the fixed cam cut-offs have the preference.

Perhaps some day, with the rivers locked and navigated more steadily, more costly fuel and greater necessity for economy in that item, our engineers and owners may be educated to the benefits from a properly used variable cut-off.

Mr. Dickie:—Have any of these river steamers of very light draught been tried with turbine-wheels instead of stern-wheels?

Mr. Roelker:—Referring to the question of backing a boat

off from the bank, I would say: The propeller will probably not do as well as many might think. A propeller has comparatively little power when backing or going ahead while fastened to a stationary point. It gets its power when the boat moves fast through the water in connection with a high number of revolutions. The great advances which have lately been made in obtaining power out of propellers have been made on vessels of high speed. When the vessel is stationary, a propeller gives comparatively little power, even with a high number of revolutions.

MR. SWEENEY:—In reply to Mr. Dickie, I do not know of such a wheel having been tried, nor do I know of feathering-wheels having been tried on stern-wheel boats on the Mississippi River. At one time we started to build steel wheels on stern-wheel boats, because we thought we could get them lighter than wood wheels, and they were originally constructed lighter; but we found in a little while that the ice or drift, or running the wheel on the shore, destroyed it, or bent it so that we had to build it stronger; and even then the wheels were not entirely satisfactory. That resulted in abandoning the steel wheels and going back to the wooden wheels, because presently the steel wheels got heavier than the wooden, and when they were bent would interfere with the use of the wheel until straightened again; while a wooden arm or bucket may be broken out, and the boat goes on about her business until the usual "lay-over" allows repairs to be made. There is no doubt that feathering-wheels would give very much better results as to speed, but I have never been able to get on well with its introduction, because the owners doubt the ability to keep it in repair. As you know, those streams carry with them a great deal of sediment, and that is very liable to make excessive wear. I know of one boat at New Orleans running with feathering-wheels where that has been the objection.

MR. RAYNAL:—Have any twin-screw boats been tried?

MR. SWEENEY:—No, not that I know of.

MR. RAYNAL:—Do you think that the same objections would hold good with twin-screw boats?

MR. SWEENEY:—Yes. Two screws would give twice the trouble that one would.

A MEMBER:—How about snags?

MR. SWEENEY:—They do not bother the wooden wheels, because any "wood butcher" could fix the wheels. The experience has not been great with screws, but so far snags are their deadly enemy.

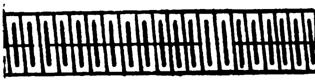
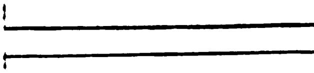
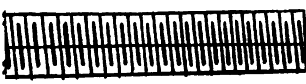
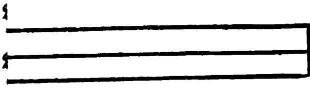
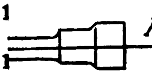
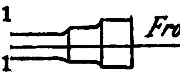
MR. WARD:—I would like to supplement Mr. Sweeney's remarks in regard to these steamers. They do seem most peculiarly

Mr. Milton cannot compare jumping according to methods of construction, with jumping at the gradations of thickness: no one would, I think, advocate the same constant for single-riveted lap-seams in a furnace, as for single-riveted double butt-strap seams; but why have a sudden jump at the thickness $\frac{9}{16}$ inch. Suppose it is a hair over $\frac{9}{16}$ inch, are we to jump or not?

Regarding stress allowed on tube-plates, I regret an error did exist in the manuscript, which I hope can be corrected in the final report: the stress should be 10,000 lbs. per square inch for Board of Trade, and 12,800 for Lloyd's.

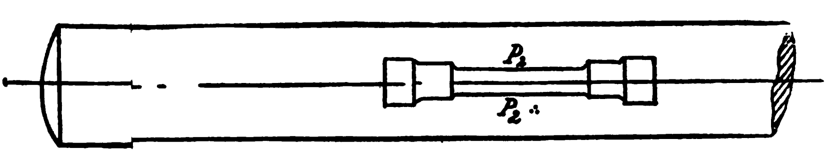
In conclusion, I may say that I certainly agree with Mr. Milton's final paragraphs, not expecting that all my conclusions can be received as correct, and knowing that in most cases there must be arguments well worthy of consideration on the other side. My conclusions just referred to, as stated at the outset, have been given in order to draw forth the opinions of others. Such exhange of ideas is often a fruitful source of knowledge, and therefore a benefit to the profession to which we belong.

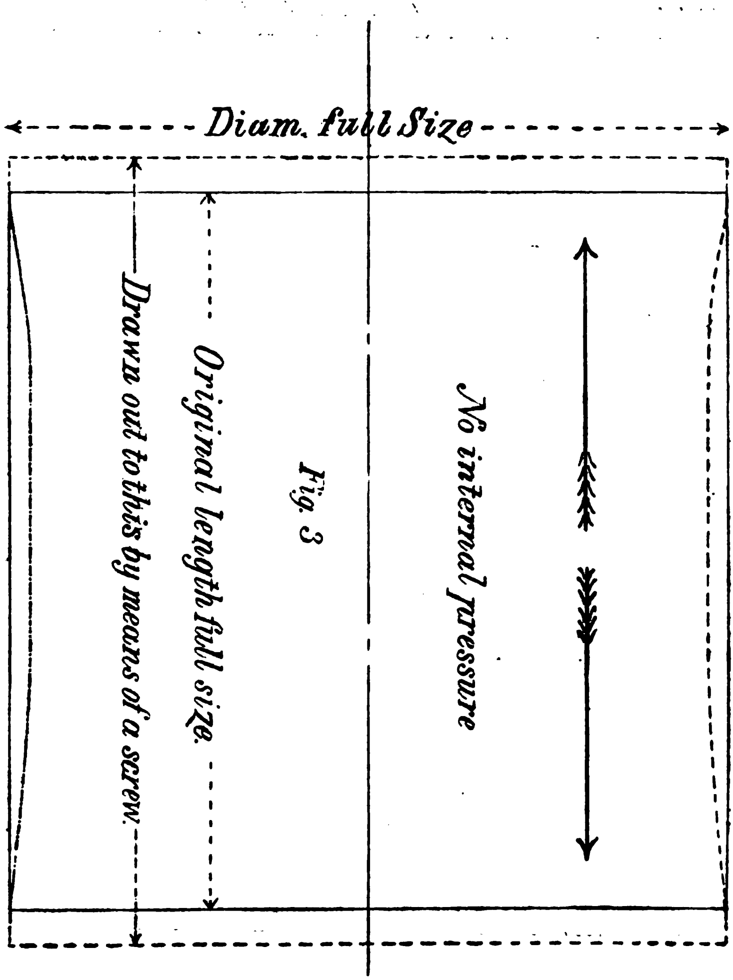
…YS, AND BOLTS.

Mark.	T…	Description of Test Bar.
B		 *Screwed 12 threads per …* *Whitworth thread*
C		
E		 *The same bar with threads turned off.*
F		
G		 *Screwed 7 threads per inch Whitworth thread.*
H		
A	1	 *The same bar with threads turned off.*
D	1	
T_1	1	 *From upset part of stay. See below*
T_1 ∴	1	
P_1	1	*From body of stay unworked*
P_1 ∴	1	
T_2	1	 *From upset part of Bolt head. See below*
T_2 ∴	1	
P_2	1	*From body of Bolt unworked*
P_2 ∴	1	

LARGE BOLT.

… upset by hydraulic Pressure.




Diam. full Size
No internal pressure
Original length full size.
Drawn out to this by means of a screw.
Fig. 3

strated that flue thickness should be based on the length of the flue. It was from this hint to the Board that the flue rule as it now stands grew, because satisfied without looking further into the matter, the Board took up the Fairbairn formula, to which their attention had been attracted, and adopted it as their rule.

At several meetings of our Board of Supervising Inspectors there has been some faulty legislation, and it has been suggested to some members, without favorable result, however, that, where they make radical changes in the requirements, the measure should be merely introduced at one meeting, and lie over until the next year's meeting, so that they might be able to be advised fully in the mean time of the probable effect.

There is now a rule of this board which requires what we call manhole openings to be reinforced. Lately there has been used an arrangement of manhole opening which turns a flange around the opening into the boiler, and the advantages of the method are well recognized. Under the rule which was adopted by the Board of Supervising Inspectors at their meeting before the last one it is impossible to use that plan, because the rule requires that we must put around the opening a band equal in contents to the material cut from the plate, this band being riveted to the flat plate in case of flat surfaces. It is evident that the flange turned around the opening makes much the strongest and most satisfactory work, but is not in accordance with the letter of the rule, and therefore not allowed.

MR. OLDHAM :—For a moment I think I may be allowed to take the side of the supervising inspectors, and I will just do that by relating a little story which occurred in connection with a registration society. They, of course, are somewhat arbitrary at times.

There was a ship-builder, and he was very anxious to make a good ship, and to get as strong a plank as possible ; he got a very large plank, and gave it a shear, and got that plank all in one length, and he thought he had done a very handsome piece of work; but when the inspector came in, with his usual officious manner, he said: "What is this, Mr. Jones? You have a plank here without a butt." And the builder said : "Yes, I have taken a great deal of trouble about making the sheer-strake of one length." "But," the inspector said, "there must be a butt for every three planks, and you must saw that plank to comply with the rules." This is a fact, that the ship-builder relates to this day. I think it exactly coincides with Mr. Dickie's story, though I presume the standard of twenty-six hundredths ($\frac{26}{100}$) of an inch cannot possibly refer to the diameter, only to the length of flue, I suppose.

MR. DICKIE:—It was a plate on which the fire impinged; and that was the law then.

COL. E. A. STEVENS:—The subject of the inspection laws of this country is one on which there was considerable discussion at the session of the last Congress on the introduction of the bill by Senator Frye to amend those inspection laws. That bill, in which some of the members present were interested on both sides, attempted to regulate such matters by an act of Congress. We all know the unsatisfactory condition of the law. I suppose any of you gentlemen who have overhauled old vessels, especially wooden vessels, have very often to stretch your imagination to find the 8 inches between the bottom of your boiler and the top of your keelson. I have had inspectors who did not seem to understand whether the discharge from the condenser were going to the bottom or side of the vessel, as required by law. We have all had those experiences; but what has been the most provoking and probably the most irritating to the ship-owner—and I am talking from that standpoint at the present time—are the restrictions laid on us about matters which have become matters of statutory law, which cannot be altered by any Board or by anybody except the United States Congress; and we all know what it is to get an act of any character through Congress. I can give you a slight example. The anchorage in New York Harbor, for instance, was a matter very much abused. The transit was almost blocked by anchorage vessels; at the same time it took Congress years to legislate on that subject, though there was a great deal of effort put forward by the parties interested. What is most needed, what we must eventually come to, is some amendment to the present law; there is no question about that. Of course there are differences of opinion; but if you take the advance that is being made in marine practice every day,—take for instance what we considered a few years ago the proper thickness for a tube-sheet: now Mr. Yarrow arises and says we are all wrong; we must have very much thinner tube-sheets; there is the point of danger. The line of improvement lies in the selection of proper, competent men to make those regulations into a system sufficiently elastic to meet the advance of engineering science.

MR. JOHN C. KAFER:—The paper of Mr. Foley's is an especially valuable one on account of collating all the data as to the rules of building boilers in different countries, and it shows that a great deal of time and care has been expended on this paper. There are some matters on which I would like to speak, one of which is the factor of safety. The factor of safety which he gives there is rather high from the standpoint of usage in this country, although we have a

factor of safety—under the Treasury Department rules—in our boilers of 6, reduced again to 5 by means of the 20% allowance for drilled holes; yet when you take into consideration the ordinary value of the riveted joints reducing it again, we have a number of boilers working for years with safety that have been operated with their maximum pressure allowed, with the factors of safety of 3½. With that in view, and with that experience at our hands, I think that the factor of safety might be safely reduced to a reasonable limit of 4, taking into consideration all the other conditions. If we increase the factor of safety, it ties us down to an increase of weight—ties us down in many ways to the increased cost of building these boilers, so that it handicaps us in various ways. If by our experience we know that a factor of safety that is lower than that is absolutely safe and has been safe; if the experience is that not one boiler has exploded with any kind of fair treatment,—then I think it would be perfectly safe to adopt a factor that experience has shown is sufficient.

In reference to the shape of test-piece, that adopted by the United States Treasury Department does not give a fair test of the quality of the material and its ultimate tensile strength. The test-piece usually adopted by manufacturers is 8 inches in length, and the ultimate strength of material in this test-piece is less, as a rule, than that in the Treasury Department test-piece. A comparison can be made when using the same shape of test-piece, but to determine the ductility it is generally conceded that the 8-inch test-piece is the better. My own opinion is that the test-piece should not be fixed at a length of 8 inches but should be proportionate to the sectional area of the test-piece, say 8 times the mean of its width and thickness.

It would, no doubt, be better in determining the strength of boilers to take the elastic limit of the material instead of its ultimate tensile strength, for the purpose of determining the pressure to be allowed in the boiler, as, after a piece of metal has been strained beyond its elastic limit, the shape of the boiler would be materially changed.

My own opinion is that Mr. Foley is in error when he states that the length of a boiler affects the strength with internal pressure. I have no doubt that between the seams the boiler would bulge out like a barrel when subjected to a pressure near the rupture point; but this is due more to the increase of strength at the joints. Wherever there is a circumferential seam the metal is in double thickness, and consequently the boiler is strong at that point. Between these circumferential seams, the boiler being of single thick-

ness, it would be apt to give way there, and to show it before bulging out between the circumferential laps.

MR. McFARLAND:—I only want to speak on one thing that my friend Mr. Kafer mentioned, and that is in regard to the factor of safety, as I was interested in some parts of the Frye bill. That very question as to what should be the factor of safety came up, and after giving the matter a great deal of careful attention and thought, we advised that the factor of safety should be made the same as recommended by the British Board of Trade, namely 5. Now the very fact came to our notice that Mr. Kafer has called attention to, that, owing to the Supervising Inspector's rules, although there is nominally a factor of safety of 6, by means of the allowance for double riveting it is brought down to 3½ and sometimes less. The question then naturally arises, "If it is absolutely necessary to have a factor of safety of 5, why do not these other boilers blow up with factors of safety of only 3?"

Well, I happen to be located in Washington, where we do not have enough steamers to let me investigate the matter personally; but, very curiously, in the first two cases that did come under my notice immediately after the publication of the Frye bill, I found that the boilers were run with only about one half to two thirds the working pressure allowed by the Supervising Inspector's certificate. They had nominally a factor of safety of 3½, but they really had a factor of safety of 7 with half the working pressure.

I asked a friend of mine who was in New York to take every opportunity he had when on board any steamer to look up that question and to find how near to the working pressure allowed by certificate to the vessel the pressure actually carried was. That was the partial solution of the question that occurred to me; that, although the factor of safety would be so low if they carried the working pressure allowed by certificate, as a matter of fact they do not carry so much pressure, and so were really running with a factor of safety of 5 to 7.

COMMODORE LORING:—Where was that?

MR. McFARLAND:—On two boats in New York Harbor. I could not say how far this state of affairs is true generally, but I say, curiously enough, in the first two cases that I investigated, taken at random, both of them happened to be running below the allowable working pressure.

Without wishing to bring up a discussion on the strength of materials or factors of safety, it seems to me that it is worth while discussing, just for a moment, whether it is safe to run with a factor of safety lower than 5. As I understand it, in bridge construction,

XLI.

COCKS ON WATER-GAUGE PIPES; AND HEIGHT OF WATER OVER HIGHEST POINT OF HEATING SURFACE WHEN SHOWING IN GLASS.

By NELSON FOLEY, Esq.

Among questions which may assume an international character, I have been requested to bring forward that of "cocks" on the stand-pipes of "water-gauges," as a subject well worthy of discussion. In doing this, it has appeared to me opportune to have opinions also expressed on the most judicious height the water should be over flame-box tops, or whatever is the highest point of heating surface, when it first shows in the glass.

Referring to the matter of the cocks: it does not seem to be necessary to ascertain which controlling agencies advocate one system and which the other; it appears to be rather a question of choosing between two evils.

Cases have arisen where the presence of these cocks have led to disaster by their being either accidentally, or owing to some mistake, closed when they should have been open. It is a common practice to close these cocks when putting in a fresh glass in addition to the cocks on the water-gauge itself, or to close them on the breaking of a glass, when the cocks of the gauge are not fitted with gear to work from a distance; when the glass is again ready for work it is possible that one cock of the two next the boiler may be forgotten.

I remember a case coming under my own observation of a rather different nature. The cocks had been overhauled and repacked by the fourth engineer and the plugs left in the proper position; the leading stoker, however, took the precaution to go round them all when lighting up, and by some mistake shut one. On leaving port (Singapore) all was confusion: the chief engineer and third were intoxicated, and many firemen. The boilers being very full, were priming furiously; and things were in such a condition that it was some time before

it was noticed that something was wrong in the case of one of them by the constant steadiness of the water in it. The fires were immediately drawn, when the actual state of affairs and its cause became known, and the boiler was saved by what almost might be called a fluke. It unfortunately happens that the fluke has not always taken place, and it is unquestionable that, as mistakes do and will occur, these cocks are a serious source of danger.

Let us now consider for a moment the other side of the question.

The British Board of Trade has a rule (which I believe is also not confined to it) that every pipe in connection with a boiler must have a cock or valve between it and the boiler. Broadly speaking, this is as it should be, for reasons too apparent to need discussion. Many rules have an exception; and may it not be that, referring to this one, the water-gauge fitting is a case where an exception should be made? Let us look into the circumstances.

The pipes leading to a water-gauge are solely connected to the boiler, not to any other part of the ship; they are therefore not subject to any injury from possible movement of the boiler relatively to the ship, owing to changes of temperature or the working of the vessel in heavy weather. If one of these pipes splits or gives way in another fashion, cocks or no cocks, the fires must be drawn if only one gauge is fitted. If cocks are interposed on the boiler, should the leak be a bad one, it is quite possible that the escaping steam or water may prevent access to one of them. In the case of the fracture of a glass, besides the automatic closing now so common, it is a simple matter to have gear from the cock-handles on the water-gauge itself led to a distance, so that, as far as the glass goes, the cocks on the boiler are not necessary. And now we come to the point upon which it all seems to hang. Suppose we have a blowing joint (provided it is not between the boiler and the cock), or slight defects in the brazing; if cocks are present the engineer can ease that boiler, closing his dampers, and take off the pipe to make good the defects without drawing his fires or blowing out.

It therefore comes to this: Does the facility just mentioned, the absence of which under certain circumstances might lead to serious consequences, compensate for the danger ever

present when the cocks are fitted, or does it outweigh that danger?

If a shut-off arrangement is fitted next the boiler, I would suggest that it must be a straight-through cock, and that, in the barrel between the opposite flanges, there be a small test hole, there being three corresponding ways in the plug, with the following object: To be able to close the passage to the gauge pillar and test the communication to the boiler to ascertain its freedom; to be able, on the contrary, to close the communication to the boiler and test the freedom of the remaining portions of the gauge-pipes; and lastly, to act as a guarantee that the cocks are not a source of mischief, as if turned squarely in a wrong position there will be either a blow of steam or water, or no water at all in the glass. It is not at all likely that the plug would be placed in a diagonal position, the errors of judgment or mistakes which arise not being of this description, and not at all likely to be.

Referring to the question as to the height that the water should be above the highest point of the heating surface when first showing in the glass, it should be noted that we find a very considerable range in practice; indeed, it appears to vary from 1″ to about 5″, and often without any connection with the size of the boiler.

When the distance in question is, comparatively speaking, great, it is often very aggravating for the engineer in charge, as he may be induced to draw fires when the actual situation would not cause it to be imperative.

A discussion on this subject should also be of interest, although for some time to come, at least, is not likely to lead to any similarity of action. My own system, when I am free to act, is this; to make the centre of the lowest cock of the glass level with the highest point of the heating surface. This rule has at least the advantage of simplicity, and is one which could not be forgotten.

In proposing this, I do not mean to advocate the doing away with the ordinary index, which tells the position of flame-box top, or whatever part of the heating surface may be highest, but merely to have a standard height at which to place the gauge.

With the foregoing few remarks, I invite others to express their views.

XLII.

FORCED COMBUSTION IN STEAM-BOILERS.

By JAMES HOWDEN, Esq.,

M. Inst. C.E., M.I.N.A., etc., etc., Glasgow, Scotland.

At the request of the esteemed Chairman of the Marine Engineering and Naval Section of this Congress in connection with the World's Columbian Exposition, the writer has undertaken this paper with a high appreciation of the honor conferred, though not without misgivings as to his adequately fulfilling the important task intrusted to him.

In English-speaking countries, the now general though somewhat incongruous term "Forced Draught" signifies a higher acceleration of combustion in furnaces, by a supply of air from a fan or other mechanism, than can be effected by the rarefaction of the air in a chimney-stack. The effect produced by this means, that of increased power in reduced space, very appropriately falls in with the highly progressive spirit of the age, in no department of effort more visible than in that which seeks to reduce the limitations of action imposed by time and space.

This accelerated combustion has had as yet its fullest development in the locomotive boiler, in which, since the memorable historic contest on the Liverpool and Manchester Railway in 1829, it has achieved effects so great that it is difficult to realize that within the memory of many still living the world has been revolutionized by the potent agency of the blast-pipe.

But for this powerful system of forced draught, a Rip Van Winkle might have been awakened at the present day, after

sixty years' sleep, without finding one tenth of the changes which have in this interval been the direct result of its use in the locomotive engine. The discovery that by contracting the exit end of the pipe by which the steam from the engine-cylinders was ejected, and by placing this contracted end a short distance under the base of the funnel, the most powerful effect on the combustion of the fuel was produced by exhaustion of the smoke-box, made the locomotive boiler spring at once into life and potency, and the locomotive the most wonderful of all developments of steam-power.

The locomotive boiler, after the introduction of the blast-pipe, being no longer dependent on the feeble draught of the necessarily short chimney for the means of combustion, or for the absorption and conduction of the heat of the fire gases on the few large tubes required for chimney draught, the use of a large number of small and long tubes became not only possible but necessary, so that the intense heat generated by the rapid combustion of the fuel was thus effectively and quickly absorbed. With the proportions and arrangements rendered workable by this system of forced draught the locomotive boiler thus became not only a marvel of power, but of economy.

Notwithstanding that this marvellous increase in power of the locomotive boiler by forced combustion has been before the eyes of the world for fully sixty years, yet in steamships and land boilers the effective application of forced draught is but of yesterday. It is only within the last few years that it has come to the front in marine engineering, while in stationary land boilers it is scarcely yet recognized as a feature of importance. Had this Congress been held ten years earlier, it is safe to say the subject of this paper would not have held a place on its programme.

In the investigation of the causes for this tardiness to adopt, in at least the eminently suitable field of steam-navigation, the advantages of a high rate of combustion so conspicuously shown in railway enterprise, the apparently strange neglect becomes to a great extent accounted for.

In locomotive engines, a condenser, for obvious reasons, was inadmissible, while a supply of fresh water for the boilers was always obtainable. The whole of the steam generated by the boiler of a locomotive became therefore available, in

its exhaust from the cylinders, for the purpose of forcing the draught, while the boiler, with its constant supply of fresh water, was kept in the most favorable condition possible for working safely, both at a high steam-pressure and at a high rate of combustion.

These conditions were, however, for a long period after the introduction of the locomotive, non-existent in sea-going steamships. With the ocean for a supply of water for condensation, but without any supply of fresh water for the boilers, the vital importance of economy in fuel made the use of a condenser universal, while the saline deposits in the boilers were comparatively innocuous under the temperature due to a low pressure of steam. This system of working was not inappropriate to the existing conditions in sea-going steamers, and had such a thing as forced draught been then proposed under the stimulus of locomotive practice, it would have been, and with much apparent reason, universally condemned.

In process of time the use of the surface condenser gave the means of maintaining fresh water in the boilers of sea-going steamers for much longer periods, and consequently with its use the saline deposits were greatly less. Higher pressures then became usable, and also, because of better boiler-making, safer, and by the continuous expansion of the steam through two cylinders a much higher economy was secured. At this stage, say from about 1870 onwards, the use of a safe and economical system of forced draught could have entered on a career of great usefulness, and by this time would most likely have become nearly as common on marine boilers as the blast-pipe in a locomotive engine, and steam-navigation would in consequence have been far in advance of what it is at the present day. The attention of marine engineers was then, however, sufficiently occupied with the introduction of the compound engine, and the change in boiler design and construction consequent on the rise of steam-pressure from 25 and 30 lbs. to 60 and 70 lbs. per square inch.

Though the really successful working of forced draught in either sea-going steamers or in those plying on fresh-water lakes or rivers had not been established until within the last few years, this fact has not been owing to the absence of repeated and comparatively extensive trials having been made. It would have indeed been surprising if such trials had not

presence of the Adamson ring on the outside of the furnace. This question of the strength of furnaces is very important.

In regard to the statement made that there were no cases of corrugated furnaces failing. I may state there is no end of trouble with furnaces with us, and corrugated furnaces are no exception to the rule. One of our new ships, the "Peru," has had several of her furnaces get out of shape owing to the presence of grease in the boilers. The China steamers running between British Columbia and China have had a good deal of trouble with the furnaces getting of of shape, and quite a number of them have had to be replaced. There is the same difficulty with furnaces of all descriptions, and I am prepared to indorse Mr. Howden, it being my opinion of the Adamson ring that, standing up as it does in the water, the main body of the metal is kept cool and maintains its shape and that of the furnace in its immediate vicinity, no matter what happens.

MR. J. T. MILTON:—The subject which Mr. Foley has undertaken to review is one of great importance not only to engineers and shipbuilders, but also to shipowners; the paper is one, therefore, which is likely to excite great interest. As, however, it appears to me that Mr. Foley has not dealt satisfactorily with the subject, and as some of his remarks appear to be inconsistent with others, I venture to offer a few criticisms upon his paper. I shall deal only with a few points; but while not making any remarks upon other parts of his paper, it must be understood that passing them over does not imply approval of the views enunciated. The paper is too long, however, to criticise in every detail.

At the outset it is to be remarked that Mr. Foley nowhere draws attention to the fundamental differences between the objects which should be aimed at by the rules of government departments on the one hand and those of registration societies on the other, nor does he notice the great difference between their incidence. Instead, therefore, of comparing how the various rules fulfil the conditions which have called them forth, he compares them with one another as if they aimed at the same thing, and afterwards compares them with his own ideal, which in itself, in some respects, does not appear to be a fixed quantity.

The rules of the government departments criticised by Mr. Foley are the statutes of the United States which are *enforced* in the case of all boilers of United States vessels, and those of the British Board of Trade which are *compulsory* in the case of boilers of British passenger steamers. There is no compulsion whatever for the boilers of any vessel to be built under the rules of any reg-

istration society, as classification is in all cases purely voluntary. The use of the word "enforced" in the heading of the paper is therefore misleading. It is not necessary to say more as to the incidence of the rules than that while some are compulsory in the cases to which they apply, others are always purely voluntary.

Next, as to the object aimed at by the various rules. In all cases the object of the rules is primarily to provide for the "safety" of the boilers. All the rules, therefore, are framed to fix the working pressure to be allowed, and all therefore are presumably intended to be based upon the actual strength of the boilers. In the case of the registration societies it must be borne in mind that vessels are in general classed for extended periods, in fact so long as they are found by periodieal surveys to have been kept up in good condition. It is therefore necessary that the rules for the *original* construction of their boilers, like those for the original construction of the vessel, should provide at the outset sufficient margin to insure continued efficiency for long periods when subjected to the reasonable amount of wear and tear which extended experience shows to be inevitable in all classes of boilers.

In the case of the enforced rules of government departments, however, this does not hold to anything like the same extent. It is not the business of any government to take such care of shipowners' interests as to provide for the long-distant future, but only to take such measures as will insure safety during the limited time which must elapse before the boilers to which the rules apply come again under survey. This period is rarely, if ever, more than twelve months.

Mr. Foley has not only lost sight of this great distinction between the two cases, but he expressly states, over and over again, that he objects to any provision being made in the rules for corrosion taking place, although he admits that some parts of boilers are "peculiarly liable to corrosion," and also states that "an allowance for corrosion cannot be objected to from an owner's or inspector's point of view, they being the best judges of the circumstances under which the boiler is going to work." It is unfortunate that to Mr. Foley's experience as a constructor of machinery and boilers there has not been added that of the frequent examination of boilers of varying ages, different designs, and which have been subjected for longer or shorter periods to all kinds of treatment incidental to years of service, frequent changes of engineers, etc. He would then probably have held very different views as to the desirability or necessity of providiug a margin for wear and tear in the original construction of the boiler.

by a fan in the base of the chimney, as the air used, being cold, the fan required, besides being of the smallest dimensions, was not subject to injury from the heat of the fire gases. In the year 1846 this system was fitted in the steamer "John Stevens," and in 1850 in the "John Neilson." In the first trials of this system of forced draught the air-pressures carried appear to have been high, but they gradually decreased until only atmospheric pressure was used, the fans in those steamers in which they were afterwards fitted being employed for ventilating purposes only, the boiler-rooms being no longer air-tight. This latter system, though it overcame the difficulties in working belonging to the two forms first tried, introduced very serious defects of its own, as it cannot be worked, even with the modern high-class boiler construction, much, if at all, above the power of a good chimney draught, in most boilers, without seriously damaging them. In those early days, when the construction of boilers was so much inferior, when a high rate of combustion was attempted, serious injury doubtless likewise occurred.* Though patching and calking in those days were looked upon lightly, and considered almost a matter of course, it is evident that, owing to the defects and difficulties mentioned, this and the other systems described died out in America some years after their introduction.

After this historical summary of the introduction of these modes of forced draught, so far as they are known to the writer, is concluded, it will be shown more particularly why these systems of forced draught did not eventually succeed, and why after a sufficiently prolonged experience the usual chimney draught was found to be more advantageous.

Very shortly after the system of blowing air into a closed ash-pit had been tried by Mr. E. A. Stevens in America, the same plan was tried by the Rotterdam Steam Navigation Co., in boilers of light steamboats built for service on the Moselle and Rhine. In these boats a boiler of the locomotive type was used, the air being delivered direct into a closed ash-pit by a fan on the floor of the boiler-room. Drawings of these boilers and their arrangements in the ship have been published,† which show how the fans were placed in their relation to the closed ash-pits.

* As the marine boilers used in these early steamers would doubtless have interior flues only for heating-surface, less damage would necessarily occur from the cold-air admission with the closed stoke-hold in these boilers than in the multitubular marine boilers of the present day. † *Engineer*, Jan. 23, 1891.

Two steamers having this arrangement were built in 1840 and 1841, and were besides fitted with compound engines. They form an interesting example of advanced progress in engineering at a very early date.

Doubtless some other applications, not known to the writer, of one or other of the plans already described, will be found to have been made between 1850 and 1861. In the latter year, after the outbreak of the great war in the United States, nineteen screw-gunboats were built, the machinery for which was designed by that eminent engineer, Mr. B. F. Isherwood, then Engineer-in-Chief of the Navy Department. All these boats had boilers constructed to work with air supplied by a fan into closed ash-pits, as well as with natural draught. With this exception the interval between 1850 and 1875 appears to have elapsed without any serious attempts being made to employ other than chimney draught for effecting combustion in boiler furnaces, if the use of the steam-jet in the chimney and some trials of inducing a current of air into open ash-pits and over the fires by means of a steam-jet, in the manner of a Giffard injector, be left out of account.

In 1875 Messrs. John I. Thornycroft & Co., of London, who had become celebrated for their construction of fast steam-launches and light steamboats, chiefly screws, began the construction of torpedo-boats with boilers of the locomotive type, in which, as the engines were surface-condensing, a high rate of combustion was attained by means of the air-tight boiler-room, into which air was forced by means of a fan. Their first torpedo-boat, worked in this manner, was built in 1875, and supplied to the Austrian Government. This resuscitation of the air-pressure boiler-room, and the need of a locomotive boiler (a type which, with certain precautions in working, is more favorable than the ordinary marine boiler for this system of forced draught), with the use of a high steam-pressure and a type and construction of engines designed to work at a high velocity and number of revolutions, increased the speed of these light steamers so greatly, that in a few years, by means of constant improvements in design and workmanship, the speed of these boats was brought up to nearly double what would have been considered possible but a few years before. The success of the torpedo-boats, with the high power generated in the loco-

ring to material which has in all cases a minimum elongation of 20 per cent in 8 inches. If it becomes brittle, it is not the fault of the steel, but of the manipulation and treatment it undergoes. Mr. Foley has evidently meant high and low *tensile strength* instead of high and low *quality* on pages 13, 25, 34, and 35.

Leaving the question of material, let us refer to the rules relating to details of construction. With the exception of the United States Statutes, all the rules assume that the strength of the boiler-shell depends directly upon that of the longitudinal seams, and practically all calculate the strength of this joint in the same way, from the actual diameters and pitch of the rivets. On this portion of all the rules therefore there need be no comment. In addition to varying the pressure in accordance with the strength of the joint, the Board of Trade have no less than 25 modifications of the pressure provided for in their rules, in accordance with difference of design or methods of workmanship, some of which can have no influence whatever on the strength of the boiler. For instance, according as the holes in either or both of the longitudinal and circumferential seams are drilled in place or out of place, so the pressure is varied; although in all cases it is stipulated that the holes are to be drilled after the plates are bent, and that they are all to be fair and good. What difference in the strength can exist in these cases? Yet Mr. Foley says of these and similar regulations: "the principle" . . . "is correct," on page 6; and the list is "admirably drawn out," on page 22. However, his remarks on this point are somewhat qualified on page 10, where he says: "Referring again to the Board of Trade additions, it may "well be asked why in all cases they should be cumulative." In my opinion no modification of the pressure on account of different methods of construction can be justified, unless these methods have a direct bearing upon the actual strength of the boiler.

Consider now the rules for furnaces. Mr. Foley is well aware that all rules for long plain furnaces must, in the nature of things, be approximate; but in the one feature in which the Board of Trade rule differs from the others he appeals to some six experiments, the particulars of which he does not give; and he states that their results, as measured by the Board of Trade rule, give a factor of safety ranging from 4.4 to 6.2. This is a difference of over 40 per cent, yet he calmly remarks: "therefore, . . . within the limits prescribed, the Board of Trade formula may be accepted as suitable for our requirements."

Turning now to the rules for flat surfaces. He says, page 31, "The Board of Trade rules for flat surfaces, being based on actual

experiments, are especially worthy of respect." Now the Board's rules differ in principle from those of the other rules criticised in their assuming that the strength of plates to resist buckling varies directly as the square of $\frac{1}{16}$ of an inch more than the thickness, and inversely as the surface supported minus 6 square inches, which are certainly not the results which would be expected from first principles; whereas the other rules assume the strength to vary practically as the square of the thickness and inversely as the surface supported. No details, however, are given of the experiments upon which the Board's rules are stated to be based. These rules were framed many years ago, when the number of experiments available were very few, and it is worthy of remark that Mr. Foley states that. The Chief Surveyor of the Board of Trade himself admits that "a simple rule such as the Board adopted must necessarily be incorrect outside a very limited range." As a matter of fact, within the range usually adopted there is very little difference in the application of any of the rules, but certainly if they are strained to meet the cases of extreme proportions it is not the Board's rule which would give the least unsatisfactory result. On page 31, referring to these rules, Mr. Foley says that "the jumping of the constants to new values is objectionable in the case of Lloyd's rules." As a matter of fact, the Board's own rules which he says "are especially worthy of respect" have no fewer than eight so-called constants.

On page 47 Mr. Foley gives examples of the Board of Trade rules and Lloyd's rules for tube-plates, and states that by the former the crushing stress is limited to 10,000 lbs. per square inch and also to 20,000 lbs. per square inch, while Lloyd's allow 25,600 lbs. per square inch. These last two figures are evidently slips, as by Lloyd's rules the stress is limited to 12,800 lbs. per square inch, and the first figures are correct for the Board's rules. However, commenting on the difference between these rules, Mr. Foley, who apparently objects to thick tube-plates, states that he would prefer the Board's rules for thick plates and Lloyd's for thin ones. The result of this would be to make the thick plates still thicker.

It would take up too much time to further criticise Mr. Foley's review, which, exclusive of voluminous appendixes, extends over 50 pages of print, but I hope I have shown that all his conclusions are not necessarily to be received as correct ones, and that in most of the cases in which he pronounces against any generally received rules, there are many arguments on the other side.

Mr. Nelson Foley (reply in writing after the meeting):—Mr. Sweeney's remarks appear not to require a reply. I may say, how-

derlying principles will also show more clearly the causes which must have led to the abandonment of the systems of forced draught already described. It may be appropriate also to explain here the causes which render natural-draught working less economical than the system of forced draught designed by the writer, even at rates of combustion moderate or low for natural draught, and much less economical at the highest natural-draught rates of combustion.

The conditions which govern a higher or lower economy in combustion in boiler furnaces by natural draught are given by the writer at some length in his paper "On the Combustion of Fuel in Furnaces of Steam-boilers by Natural Draught and by Supply of Air under Pressure," read at the Institution of Naval Architects, in March, 1884. These may be summed up shortly as follows: (1) In the same boiler, under normal circumstances and with equally suitable provision for air-supply, the highest evaporative economy is obtained with the lowest rate of combustion. (2) When the rate of combustion is increased beyond what may be termed the economical limit for any given boiler or group of boilers, the evaporative economy decreases rapidly after this limit is passed. (3) This economical limit or point at which it is found necessary to urge the fires to increase the combustion varies in proportion to the intensity of the draught: the stronger the draught the higher is the rate of combustion before the economical limit is passed. It is to be understood in connection with the furnaces referred to that the fire-grates are of the usual length, and of the same size for the different rates of combustion.

The several effects stated are owing to the following circumstances: (*a*) The draught of a chimney increases, for obvious reasons, in a much lower ratio than the increase of its temperature above the surrounding atmosphere: (*b*) An increased rate of combustion, under the ordinary methods of using natural draught, requires in practice an increased ratio of air-supply per unit of fuel consumed: (*c*) An increased rate of combustion necessitates, therefore, not only a greater proportionate waste of heat in the higher chimney temperature required to sustain the greater draught, but also the additional waste in the greater proportionate weight of air required per unit of fuel consumed.

The rapidly increasing wastefulness in fuel under these

conditions is well known to all having practical experience with steam-boilers.

In limiting the conditions of waste of fuel to the points just stated, it has not been forgotten that a very serious waste may also arise from the supply of air to the fuel being so defective as to permit a considerable portion of the carbon of the fuel to leave the boiler in the state of carbonic oxide. This condition, however, seldom occurs in good practice; and as it is supposed in making these comparisons that in all the different cases the boilers are properly worked, it is unnecessary to introduce the effect of this defective mode of working into the calculations.

In illustrating these effects on evaporative economy by quantitative examples, the weight of air given as required for the different rates of combustion, and also the resultant temperatures of the waste gases therefrom, must necessarily be only approximate, as tests made on one set of boilers cannot be taken as entirely applicable to another set of boilers where the conditions are different. The quantities of air capable of being supplied to furnaces of exactly the same size but in different boilers are varied by such circumstances as the height and diameter of chimney, number of furnaces connected therewith, proportional areas and sizes of flues and tubes, proportions of air-openings through bars to total area of fire-grate, quality of fuel, mode of stoking, with fires heavier or lighter, etc. As each and all of these conditions affect the results in a greater or less degree, no positive rule can be established as to quantities or temperatures, but those used in the examples following may be taken as conforming more or less correctly to ordinary conditions of working in steamships.

The following particulars of an actual marine boiler of ordinary type will serve to illustrate by definite calculations the various econòmical and practical effects produced by the different conditions of working. The boiler has three furnaces, each 3′ 7½″ diameter, and fire-grate 5′ 6″ in length over the extreme ends of the bars, or an aggregate of 60 sq. ft. of grate surface. The three following rates of combustion of 12, 16, and 20 lbs. per square foot of grate per hour with, respectively, 22, 24, and 28 lbs. of air per pound of fuel consumed and 450°, 600°, and 750° Fahr. as the respective temperatures of the escaping gases, are a fair approximation of what would

occur in practice in this boiler with natural draught and an average height of chimney. The lowest waste, that of 22 lbs. air per pound of coal, at a rate of combustion of 12 lbs. per square feet per hour, can be attained with careful working and suitable appliances.

In these three cases the following are the respective wastes of heat in British units, the atmosphere being taken at 60°, the specific heat of the waste gases at .242, and no allowance made for ash in the fuel:

(1) $12 \times 60 = 720$ lbs. fuel consumed per hour.

$(720 \times 22) + 720 = 16,560$ lbs. of waste gases per hour.

$16,560 \times (450 - 60) \times .242 = 1,562,932.8$ units of heat lost in waste gases.

(2) $16 \times 60 = 960$ lbs. consumed per hour.

$(960 \times 24) + 960 = 24,000$ lbs. of waste gases per hour.

$24,000 \times (600 - 60) \times .242 = 3,136,320$ units of heat lost in waste gases.

(3) $20 \times 60 = 1200$ lbs. consumed per hour.

$(1200 \times 28) + 1200 = 34800$ lbs. of waste gases per hour.

$34,800 \times (750 - 60) \times .242 = 5,810,904$ units of heat, lost in waste gases.

The actual loss in units of heat under these three several conditions of working is shown by the figures now given, but the comparative value of these amounts can only be fully understood by ascertaining the proportions they bear to the total heat of combustion of the several quantities of coal consumed. These proportions are as follows: Taking the total heat of combustion of the fuel without ash or moisture at 15,000 British units per pound, and the ash and moisture or non-combustible portion at 3 and 7 per cent respectively, or 10 per cent in all, the total heat of combustion per pound of coal is 13,500 units, and the percentages of loss are as follows:

(1) At 12 lbs. per square foot of grate or 720 lbs. per hour. $720 \times 13500 = 9,720,000$ total units of heat, of which 1,562,932 units, or 16.08 per cent, are lost in the waste gases.

(2) At 16 lbs. per square foot of grate, or 960 lbs. per hour. $960 \times 13500 = 12,960,000$ total units of heat, of which 3,136,320 units, or 24.2 per cent, are lost in the waste gases.

(3) At 20 lbs. per square foot of grate, or 1200 lbs. per hour. $1200 \times 13{,}500 = 16{,}200{,}000$ total units of heat, of which 5,810,-904 units, or 35.87 per cent, are lost in the waste gases.

These percentages of waste are not higher than are generally found in practice, and in many cases the ratio of loss to increase of combustion is greater in practice than in the cases given.

These examples show quantitatively how the increase of combustion by natural draught necessarily reduces the evaporative economy in steam-boilers. The percentage of waste increases also with increase of combustion under forced draught with cold air in even higher ratios than with natural draught, unless the air admissions are accurately regulated.

It may be remarked also, that though theoretically the quantity of air required should be less per pound of coal consumed with forced draught than with natural draught, at full natural-draught rates of combustion, it has not been found so by experience with cold-air supply in closed stoke-holds or other modes of so using cold air. This is doubtless owing to want of regulation and other imperfect means of working.

It will be sufficient to give a case of what is known in England as an Admiralty four-hours' forced-draught trial to show how high the ratio of wastefulness rises with closed stoke-holds. The area of grate in one furnace was 24.5 sq. ft., the coal consumed 42 lbs. per square foot per hour, the temperature of the escaping gases 960° F. The weight of air supplied to the furnace must have been over 30 lbs. per pound of coal consumed, the consumption per I.H.P. being over 2.6 lbs. Taking the air of combustion at 30 lbs. per pound of coal, the waste is as follows:

$24.5 \times 42 = 1029$ lbs. coal consumed per hour.

$(1029 \times 30) + 1029 = 31{,}899$ lbs. of waste gases.

$31{,}899 \times (960 - 60) \times .242 = 6{,}947{,}602$ units of heat lost in waste gases.

Taking the coal at the same heat value as in the cases already given, the percentage of waste is as follows:

$1029 \times 13500 = 13{,}891{,}500$ total units of heat, of which 6,947,602 units, or 50 per cent, are lost in the waste gases.

This large percentage of loss in the waste gases is even exceeded in some of these Admiralty forced-draught trials. In these cases it is evident that the average temperature of the escaping fire-gases and the weight of air used for combustion per pound of fuel consumed must be higher than in the case just given, as the coal used in these trials is the best picked Cardiff coal.

The illustrations which have been given, the writer believes, will bear out his statement regarding the manner in which waste of fuel or loss of evaporative economy in boilers occurs with increased rates of combustion either by natural-draught or forced-draught plans with cold air, other than those designed by the writer.

The fuller explanation of the causes which led to the eventual non-success of the early systems of forced draught which the writer undertook to give in the earlier part of this paper will be better understood after he has given a description of his system and a short history of his connection with combustion in steam-boilers by mechanical means.

Very early in his professional career the idea of using fan-power for combustion in boiler-furnaces occurred to the writer; but, from the first, these ideas were connected with the utilization of the waste heat from the engines in the exhaust-steam, and from the boilers in the waste heat of the fire-gases.

After the construction in 1859 and trial early in 1860 of the first marine engines built by the writer, his ideas of various further improvements in marine engines and boilers were formulated in a patent bearing date November, 1860. In the specification of this patent it was proposed to draw or force the air of combustion for the furnaces through or amongst the small tubes of a surface condenser, and thus utilize the sensible and latent heat of the exhaust-steam for the purposes of the combustion of the heat generating that steam.

Recognizing that the quantity of the air for combustion, however effectually used in the air-surface condenser, was insufficient to take up the whole of the heat of the exhaust-steam so as to produce a good vacuum, the writer included the use of a fine spray of water on the tubes of the condenser, to be drawn in with the air of the fan. The rapid evaporation of

this wet spray was to add considerably to the cooling power of the fan, while the hot vapor was to be caught up and carried by the fan to the furnaces.

It may probably be of sufficient interest to explain here that the writer at that time did not consider that in the engines he then proposed to build a high vacuum was a matter of much importance, as the steam-pressures he contemplated using were to be from 150 to 200 lbs. per square inch. The engines constructed by the writer in 1859, to which reference has been made, were for a small steamer for the Mediterranean trade of the well-known "Anchor" Line. They were compound, and used steam of 100 lbs. pressure. From the performances of these engines the writer concluded that working pressures would soon rise to 150 and 200 lbs., as mentioned; and, in order to better utilize these pressures, he proposed to expand the steam continuously through three cylinders, and the same patent in consequence contains a claim for the triple-expansion engine. This patent further contains a claim for the utilization of the heat of the waste fire gases by passing them through a tubular air-heater, in which air from a fan circulated, and after taking up the heat carried it to the furnaces. In the illustrations shown of this arrangement the air from the fan is led to the furnace above the fires, and the ash-pit is not closed.

With the exception of one application of the air-condenser to a non-condensing land engine in 1860, none of these proposed plans were carried out during the term of this patent.

The first proper trial in forced draught was made by the writer in February, 1862, in a tubulous boiler which he had constructed for the purpose of testing its evaporative power, and at the same time of testing practically the economic and other effects of forcing the combustion by means of a fan blowing air into a closed ash-pit. The fan employed had a side or axial delivery, and was driven by a steam-wheel fixed on the fan shaft, the steam having a tangential impact on the periphery of the wheel.

This boiler shown in Fig. 1 was erected with a short iron chimney in the yard in which it was built so that the combustion was chiefly dependent on the air-supply from the fan. A tank for measuring the feed-water and a pump for feeding the boiler completed the apparatus.

The trials were made with fires of various thicknesses and under various degrees of air-pressure. The weight of the water evaporated and coals consumed on each trial were noted, also the temperatures of the escaping fire-gases. The trials were completed in one week, and though not so exhaustive as later trials made by the writer, they clearly established the following general principles: When the fire was made sufficiently light to allow the necessary air to penetrate freely from the ash-pit to the upper layers of fuel and effect the combustion of the inflammable gases and greatly reduce the smoke from the bituminous coal used, the evaporative economy was much reduced, though the temperature of the waste gases was low. When the fires were made thick to prevent the air from passing too freely from the ash-pit, and a higher air-pressure used to effect a more rapid combustion, the evaporative economy, though considerably higher than with the thinner fires, was not so high as should have been with the still comparatively low temperature of the waste gases leaving the boiler. The smoke also was excessive, and though no chemical analysis of the waste fire-gases was made, they must have contained a quantity of carbonic oxide, as in no other way could the comparatively low evaporative economy be accounted for.

These trials showed that with the lighter fires and more complete combustion a great excess of the normal quantity of air per unit of fuel consumed was necessary to effect the better combustion; and further, when the fires were made heavy to prevent the air passing through so freely, the combustion was imperfect, and considerable loss was sustained therefrom.

As the furnace door was not quite air-tight, there was also the same trouble in the emission of flame and smoke at the door when the air-pressure used was high, as was found in the early trials of Mr. E. A. Stevens with this system on steamers on the Hudson.

It has been stated that the temperature of the fire-gases leaving the boiler was low even in the trials with the highest air-pressure. This is explained by the facts that the feed-water used during these trials never exceeded 44° F., and as it entered the bottom tubes as indicated in the plan and passed upwards meeting the descending fire-gases these left

the boiler where the water in the tubes was always considerably below the boiling-point.

After the conclusion of the trials the writer formed a very decided opinion, which his subsequent experience has confirmed, that no advantage arising from increased combustion over natural-draught rates was to be derived from using forced draught in a closed ash-pit sufficient to compensate the disadvantages arising from difficulties in working, there being either excessive smoke from bituminous coal or reduced evaporative economy. He accordingly gave up making further attempts in this direction at that time. Many years afterwards, when the trials of the torpedo-boats with air-tight boiler-rooms under pressure began to attract attention, the writer remembered the results of his trials of 1862, and it appeared to him that though this system got rid of some of the objectionable features of blowing into a closed ash-pit, it could not fail to be wasteful and injurious to the boiler if, on opening the furnace-door, the cold air under any considerable pressure could reach the boiler-plates or tube-ends.

In thinking over these things the writer was led early in 1880 to design the arrangement which he has worked for the last eleven years. This design was intended to overcome the defects of both the closed ash-pit and closed stoke-hold systems in making the furnaces easily workable from the lowest to the highest possible rates of combustion, in securing the highest possible economy in fuel, and in preserving the furnaces and interior parts of the boiler from injury arising from any inrush of cold air. Each of these important objects has been very successfully attained.

The means by which these objects were obtained was by first placing an air-tight reservoir or chamber on the front end of the boiler and surrounding the furnaces. This reservoir, which projects from 8 to 10 inches from the end of the boiler, receives the air under pressure, which is passed by the valves into the ash-pits and over the fires in proportions exactly suited to the kind of fuel used and the rate of combustion required. The air used above the fires is admitted by its valve to a space between the outer and inner furnace-doors, which swing on one hinge, the inner being the proper door of the furnace, having perforations and an air-distributing box through which the air under pressure passes into

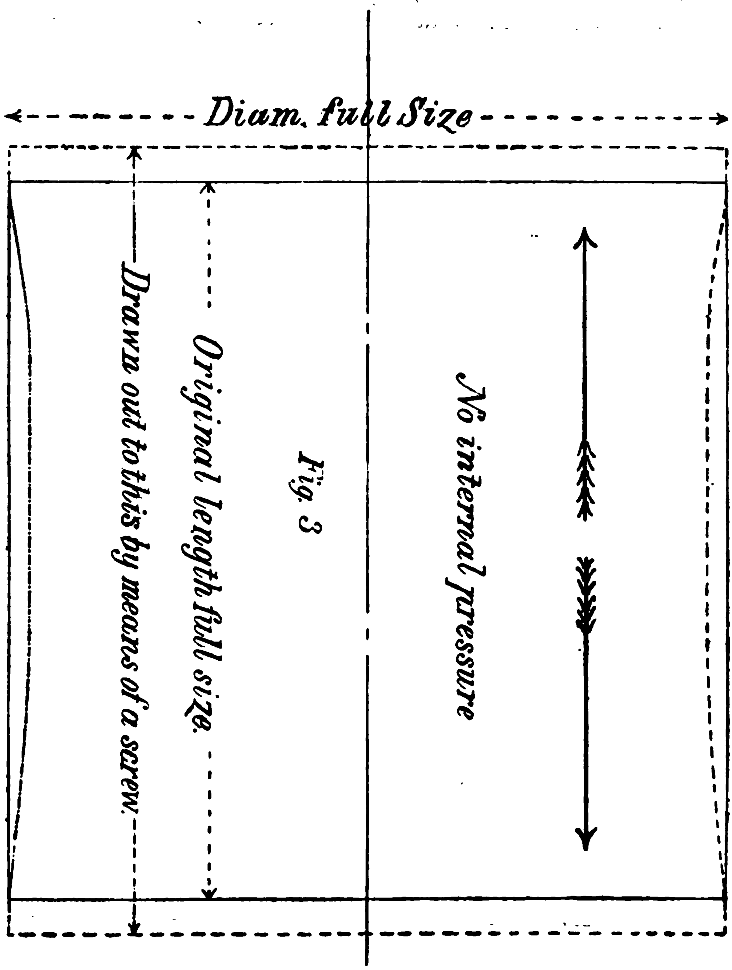
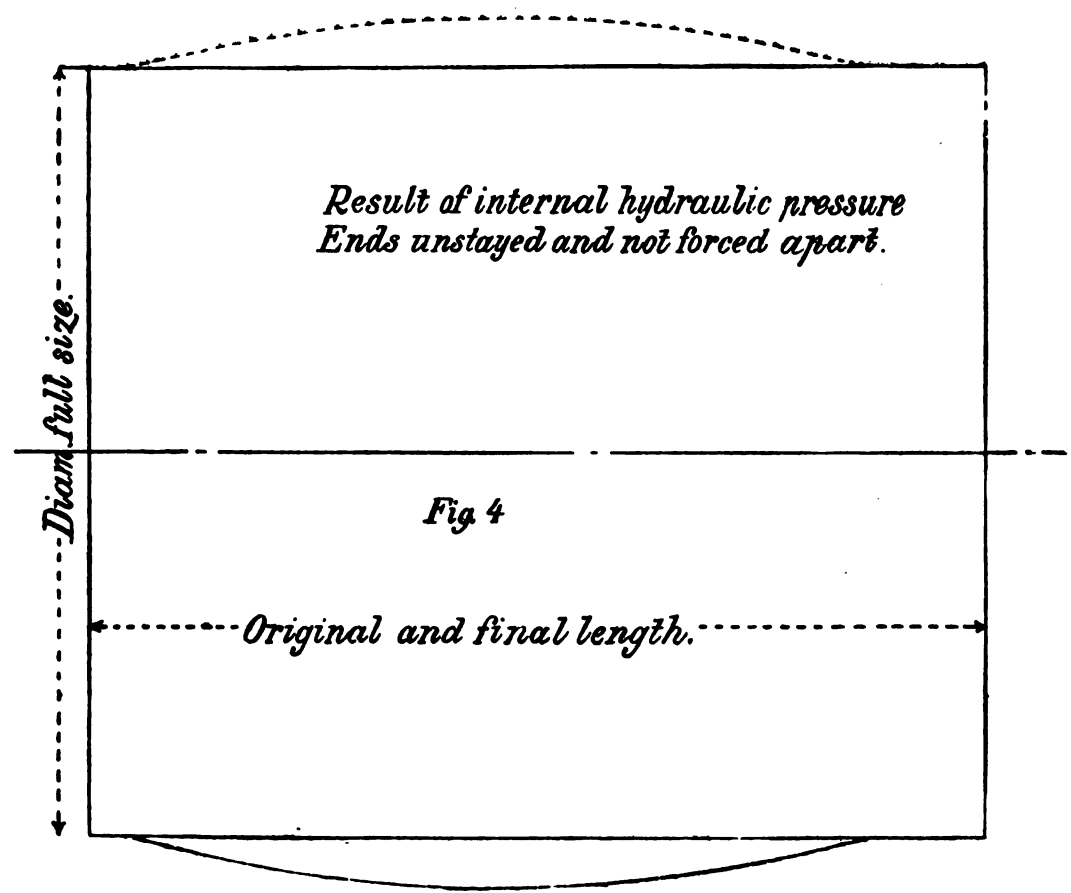

Diam. full Size
Drawn out to this by means of a screw.
Original length full size.
No internal pressure

Fig. 3


Result of internal hydraulic pressure
Ends unstayed and not forced apart.
Diam full size.
Original and final length.
Fig 4

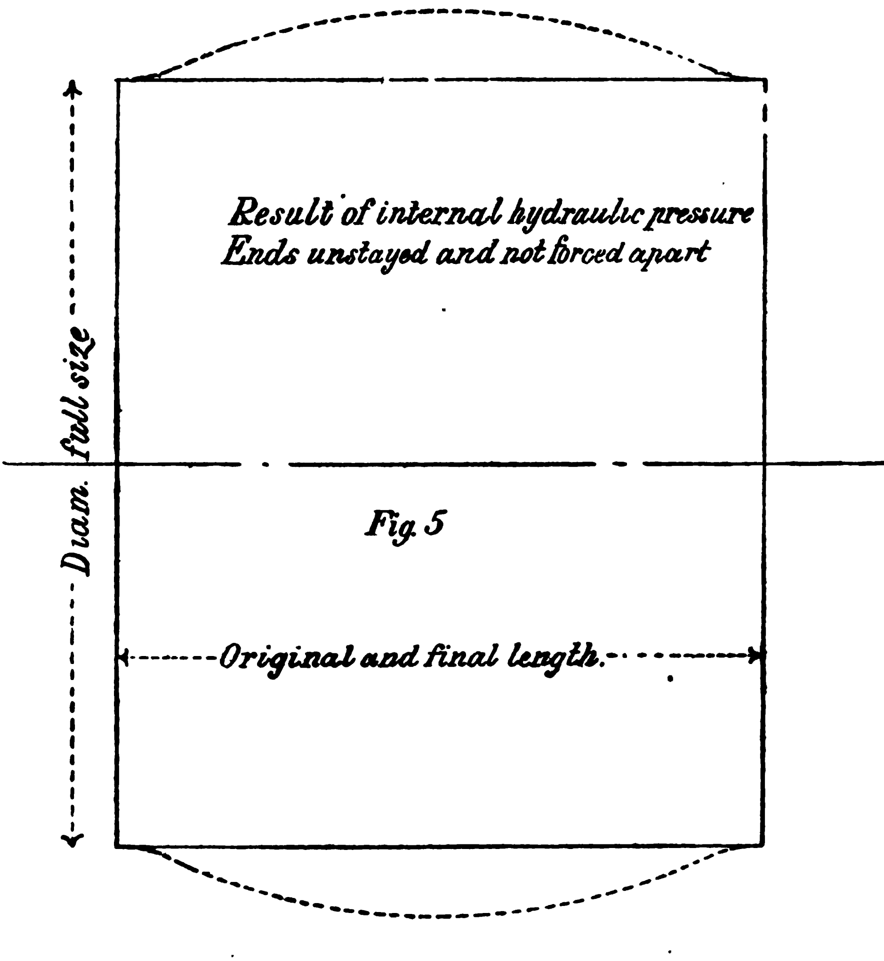
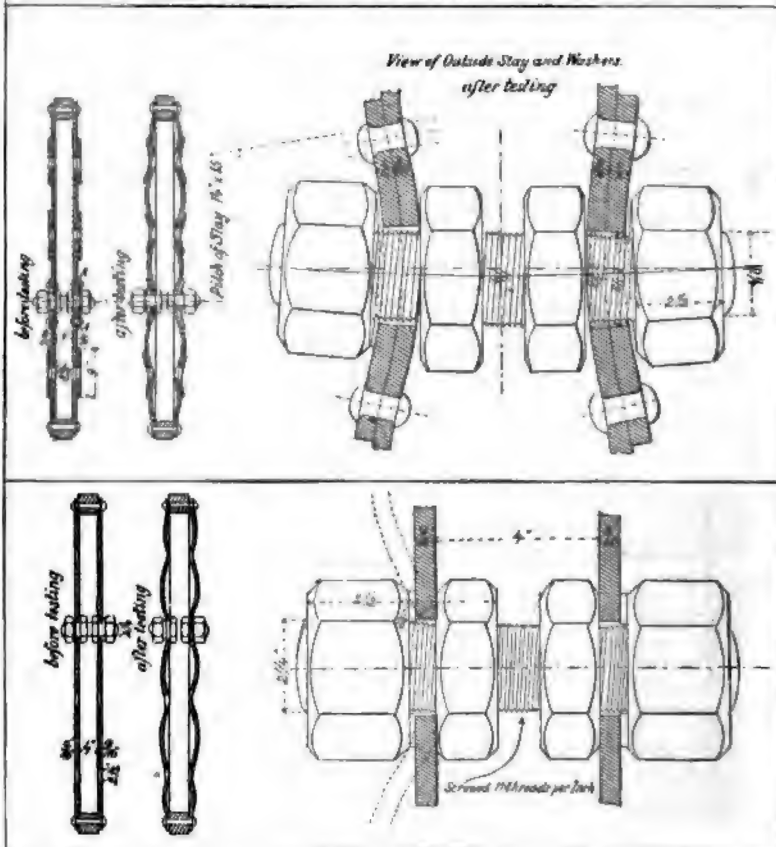
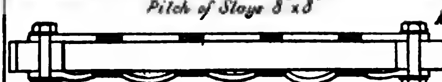

Result of internal hydraulic pressure
Ends unstayed and not forced apart
Diam. full size
Original and final length.

Fig. 5

TO ILLUSTRATE THE BEHAVIOUR UNDER EXTREME CONDITIONS.



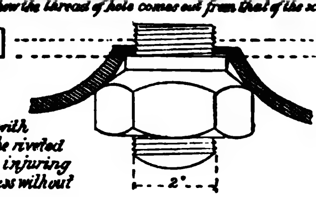
Pitch of Stays 8" x 8"



13/32 inch Steel plate.

<u>The stay were fitted with nuts, see sketch to right</u>

Showing how the holes became enlarged and how the thread of hole comes out from that of the screw



Similar experiments with boxes fitted with screwed Stay with riveted heads, showed results somewhat the same; when the riveted heads did not break off, the plate slipped over it without injuring the thread: the load borne however was naturally much less without nuts than with them.

vinced that however high the rate of working may eventually rise to, it would be quite safe for the boilers and fittings, on present experience, to work with his system up to 30 I.H.P. per square foot of fire grate with ordinary triple-expansion engines.

It will be appropriate to give here particulars of what is actually being accomplished at sea with such boilers as the one given in the illustration, which is arranged for what in future will probably be termed the moderate rates. These boilers, as has been mentioned, are fitted in the well-known steamers "Indiana," "Illinois," and "Pennsylvania." These steamers have each a single boiler of the size shown and dimensions given, the single boiler of three furnaces having in each ship replaced three double-ended boilers with eighteen furnaces. The "Indiana" was refitted at Glasgow with new machinery about three years ago by the writer's firm, and the "Illinois" and "Pennsylvania" fully a year afterwards at Philadelphia by Messrs. William Cramp & Sons, the boilers and their forced-draught arrangements being made to drawings and instructions supplied by the writer. The boilers were designed to work to 1200 I.H.P. at sea, but they have worked as high as 1400 I.H.P. on occasions.

The writer has seen diagrams from the "Indiana," taken during her eastward voyage with American coal (which is not so easily burned as Cardiff or Scotch coal), of 1370 I.H.P. As this power does not include that of the auxiliary engines and fresh-water evaporator supplied with steam from the main boiler, it is evident that with the arrangement shown in the illustration such boilers with the writer's system can be worked at sea without trouble at rates of combustion giving from 24 to 25 I.H.P. per square foot of fire-grate. It should be mentioned that the actual working grate is only 50 sq. ft. in area, there being close plates fitted at each side of the furnace to limit combustion there. The 56.5 sq. ft. measurement includes these side plates. The "Indiana" has engines having cylinders 22½", 35½", and 58½" diam. and 39" stroke. The fan supplying air to the boiler is 54" diam., and is made by the B. F. Sturtevant Co. of Boston.

The principles on which the forced-draught system of the writer is based, and the mode in which it is carried out in

practice, having now been described, a short account of its introduction to sea-going steamers may be of interest.

The arrangement, as mentioned, was designed early in 1880, but it was not until June, 1882, that the writer had an opportunity of testing it, which was first done in a small two-furnace marine boiler, which he purchased for the purpose. This boiler was erected in the writer's works, and various trials made, which from the first were so satisfactory, that he built a larger boiler for carrying out experiments on a more extended scale. These experiments were carried on at short intervals through the latter half of 1883 and the first half of 1884, and afterwards occasionally as required. These trials, up to February, 1884, and the mode of carrying them out, are partly described in the paper read by the writer at the Institution of Naval Architects in April, 1884. They enabled him to proportion the air admissions above and below the fuel at various pressures and for various rates of combustion, The relative proportions obtained by these experiments have formed the basis on which all subsequent applications of forced draught in steamships have been made by the writer. In April, 1884, the writer contracted with Messrs. Scrutton, Sons & Co., London, to refit the steamer "New York City," of their "Direct" West India Line, with a boiler fitted with forced draught. This steamer had compound engines with cylinders 33″ and 61″ diam. and 33″ stroke, worked with steam of 80 lbs. pressure. The original boilers, which had been in use for five years, were in two parts, placed back to back, so as to form a double-ended boiler with a common combustion-chamber. There were two furnaces in each end, having an aggregate grate surface of 75 sq. ft., while the heating surface in the tubes was 2173 sq. ft.

The new forced-draught boiler was single-ended, having three furnaces with a total grate surface of 36 sq. ft. after deduction of side bars, and 37.5 sq. ft. including side bars. This boiler was first tried under steam in September, 1884, and had afterwards a successful forced-draught trial before loading in the estuary of the Clyde on October 1, and eventually, after loading, another very satisfactory trial on October 13, on which day she sailed direct for Trinidad, which she reached after a successful run without stoppage. As the engines had not been in any way altered during the refit,

XLI.

COCKS ON WATER-GAUGE PIPES; AND HEIGHT OF WATER OVER HIGHEST POINT OF HEATING SURFACE WHEN SHOWING IN GLASS.

By NELSON FOLEY, Esq.

Among questions which may assume an international character, I have been requested to bring forward that of "cocks" on the stand-pipes of "water-gauges," as a subject well worthy of discussion. In doing this, it has appeared to me opportune to have opinions also expressed on the most judicious height the water should be over flame-box tops, or whatever is the highest point of heating surface, when it first shows in the glass.

Referring to the matter of the cocks: it does not seem to be necessary to ascertain which controlling agencies advocate one system and which the other; it appears to be rather a question of choosing between two evils.

Cases have arisen where the presence of these cocks have led to disaster by their being either accidentally, or owing to some mistake, closed when they should have been open. It is a common practice to close these cocks when putting in a fresh glass in addition to the cocks on the water-gauge itself, or to close them on the breaking of a glass, when the cocks of the gauge are not fitted with gear to work from a distance; when the glass is again ready for work it is possible that one cock of the two next the boiler may be forgotten.

I remember a case coming under my own observation of a rather different nature. The cocks had been overhauled and repacked by the fourth engineer and the plugs left in the proper position; the leading stoker, however, took the precaution to go round them all when lighting up, and by some mistake shut one. On leaving port (Singapore) all was confusion: the chief engineer and third were intoxicated, and many firemen. The boilers being very full, were priming furiously; and things were in such a condition that it was some time before

it was noticed that something was wrong in the case of one of them by the constant steadiness of the water in it. The fires were immediately drawn, when the actual state of affairs and its cause became known, and the boiler was saved by what almost might be called a fluke. It unfortunately happens that the fluke has not always taken place, and it is unquestionable that, as mistakes do and will occur, these cocks are a serious source of danger.

Let us now consider for a moment the other side of the question.

The British Board of Trade has a rule (which I believe is also not confined to it) that every pipe in connection with a boiler must have a cock or valve between it and the boiler. Broadly speaking, this is as it should be, for reasons too apparent to need discussion. Many rules have an exception; and may it not be that, referring to this one, the water-gauge fitting is a case where an exception should be made? Let us look into the circumstances.

The pipes leading to a water-gauge are solely connected to the boiler, not to any other part of the ship; they are therefore not subject to any injury from possible movement of the boiler relatively to the ship, owing to changes of temperature or the working of the vessel in heavy weather. If one of these pipes splits or gives way in another fashion, cocks or no cocks, the fires must be drawn if only one gauge is fitted. If cocks are interposed on the boiler, should the leak be a bad one, it is quite possible that the escaping steam or water may prevent access to one of them. In the case of the fracture of a glass, besides the automatic closing now so common, it is a simple matter to have gear from the cock-handles on the water-gauge itself led to a distance, so that, as far as the glass goes, the cocks on the boiler are not necessary. And now we come to the point upon which it all seems to hang. Suppose we have a blowing joint (provided it is not between the boiler and the cock), or slight defects in the brazing; if cocks are present the engineer can ease that boiler, closing his dampers, and take off the pipe to make good the defects without drawing his fires or blowing out.

It therefore comes to this: Does the facility just mentioned, the absence of which under certain circumstances might lead to serious consequences, compensate for the danger ever

the early part of the year 1886, contracted with the writer's firm to convert the compound engines of their steamer "City of Venice" into quadruple-expansion engines, having their steam from two forced-draught single-ended boilers 14′ 0″ diam. by 10′ 10″ long, and of 150 lbs. pressure, with 6 furnaces, instead of the four boilers previously used with 12 furnaces. The new engines were to work from 1600 to 1800 I.H.P. at sea as required, the power of the compound engines and boilers at sea having been 1300 I.H.P. This contract was successfully accomplished, the steamer being tried in January, 1887; and since that trial all other steamers of Messrs. George Smith & Sons which have been refitted, and every new steamer they have built, have been fitted with the writer's system of forced draught.

The writer desires to put on record events which occurred at this time, illustrating the fact that Americans are freer from the trammels of that conservatism which is founded largely on prejudices than are his own countrymen.

While the British steamship owners were dubiously looking at this new mode of greatly increasing the power of their steamships, which at the same time much reduced the rate of fuel consumption as well as the weight of the boilers and the space they occupied, the writer was visited in Glasgow in February, 1886, by Mr. James S. Doran, Superintendent Engineer of the "American" Line of steamships, who had been sent from Philadelphia for the purpose of inquiring into this matter of forced draught, reports of which had reached the President, Mr. C. A. Griscom, and the Directors of his Company.

The writer trusts he will be pardoned for taking this opportunity of expressing his opinion regarding this Company as one representative of the highest type of American enterprise and one to which the ship-building and engineering world owes much for the impulse they have given towards higher attainments, by their readiness to adopt improvements in order to keep in the front of the most advanced naval and engineering practice of the day.

As the "New York City" was about due in London at the time, and required to make a short run from thence to Cardiff for a cargo of coal, Mr. Doran was enabled, by making this short run, to see the forced draught in that steamer in oper-

ation. Had Mr. Doran listened to the reports of some engineers who had plenty to say on the subject but who knew little or nothing about it practically, he would doubtless have returned to America with an unfavorable report. Being, however, well able to judge of its value after having seen the system in operation, the issue was, that later in the same year his company contracted with the writer's firm for the complete refitting of their steamship "Ohio" with new engines and boilers designed by the writer, the boilers being fitted with his forced-draught system. This contract, which was undertaken with the guarantees of 2100 I.H.P. on a consumption of coal not exceeding 1.25 lbs. per hour on a lengthened trial, was satisfactorily accomplished on the completion of the refit of the steamer in June, 1887. The Company having during 1886 come into possession of the well-known Inman fleet, had likewise contracted towards the end of that year with Messrs. Laird Brothers of Birkenhead for the refitting of their steamer "City of Berlin," the boilers of which, though not built or arranged in this ship to the plans of the writer, were fitted by that firm with his system of forced draught.

After fully two years' experience of working the "Ohio" the Company contracted with the writer's firm in 1889 for the refitting of their steamer "Indiana," the particulars of which have already been given. Before the "Indiana" was completed in the latter part of 1890 the Company again contracted with the writer's firm for the converting of the steamship "City of Paris" from the closed stoke-hold system to his system of forced draught. This undertaking presented special difficulties in being carried out, as the arrangement of pipes and other fittings could only be partly altered to suit the new system, while the structural arrangements of the ship could not in any way be altered. One of the difficulties which was eventually found to render the fans much less effective than in ordinary installations or than the writer anticipated, was that, owing to arrangements of details which could not be altered except at great expense, the discharge passage from the fans on the main deck to the boilers below could not be made in a continuous pipe, but in alternatively larger and smaller portions with awkward connections to the air-heaters on the boilers. The effect of these passages was to dissipate considerably the power of the fans, while a deficiency in area

in one part of the boilers themselves very much reduced the power of combustion in the furnaces of that steamship. The causes of the reduced efficiency were not, however, apparent or easily discovered, being greatly masked by the indication of sufficient air-pressure in the ash-pits.

This was a unique case, and the writer learned much from the exceptional behavior of the boilers of this steamship, especially regarding the causes and conditions which limit the power of combustion under certain circumstances, though a considerable period elapsed before he found a complete solution of the apparent by anomalous results. At the end of the first season after the alteration to the writer's system, the air-passages from the air-heaters to the furnaces were somewhat enlarged. The combustion was increased by the greater weight of air passing through the fuel, though strangely the air-pressure was not thereby sensibly increased in the ash-pits. This phenomenon arose from the fact that when the air admitted by the valves to the ash-pits does not pass quickly through the fuel it rapidly increases in temperature, and also in pressure, so long as the cooler air in the reservoir above is of a higher pressure, which it invariably is. This air-pressure, which is caused by local increase of volume, consequently reduces the weight of air passing through the furnaces, and also the rate of combustion.

The combustion under such circumstances is still further reduced by the proportionately greater quantity of air entering over the fires tending to increase the pressure above, which, with the contracted area previously mentioned, hindered still further the passage of the air through the fuel below.

These were the circumstances which prevented the normal development of the forced-draught power in the "City of Paris," and which makes her as now fitted a much lower example of the writer's system than the "Indiana" and her sister ships belonging to the same Company. It must, however, be remembered that though thus handicapped this steamship has made the fastest passage on record to this date from Queenstown to New York, the time being 5 days 14 hours and 24 minutes on a passage of 2782 nautical miles, though the grate-bars are 13 inches shorter in length than when working with the closed stoke-hold, while the acting grate surface is

still further reduced by the close side bars being considerably wider with the writer's system.

The effect of the special causes mentioned as restricting the fan efficiency in this steamship, and consequent air-supply and rate of combustion, is strikingly exemplified in the burning of Welsh and American coal on the westward and eastward voyages. The latter coal requires considerably more air than the former, and consequently on the eastward passage it is well known her power and speed are considerably under that of the westward passage. That this result is entirely due to the causes mentioned is clearly shown from the power obtained in the boilers of the "Indiana" and sister ships. Though the fan power is much less in proportion in these ships, yet being effectively applied, the rate of combustion is much higher. In these steamers as much power is obtained from American coal as from Cardiff coal. All that is necessary to insure an equal combustion from American coal is to speed the fan somewhat higher.

It has been already stated that from the "Indiana" on the eastward run with American coal the writer has had diagrams of 1370 I.H.P. taken in ordinary course. The proportionate power of the "City of Paris" would be fully 26,500 I.H.P.; but while the proportionate heating surface at these powers is in the "Indiana" only 1.63 sq. ft., it would be in the "City of Paris" 1.89 sq. ft., per I.H.P. That the boilers of the "City of Paris" could as easily attain a proportionate power as that of the "Indiana," if placed as favorably as the latter, is as certain as the invariability of natural law.

From the latest experience of the writer he is convinced that with boilers of even smaller capacity than those of the "City of Paris" a greater power than 26,500 I.H.P. could be taken with less difficulty than 20,000 is taken now from the boilers of this steamship, and with one half the number of fans now used, and not more than two thirds of the present fan-power.

It is unnecessary to extend greatly the account of the introduction of the writer's system. The "White Star" Line applied it to their mail-steamer "Celtic" at the end of 1886, and eventually to the "Teutonic," "Majestic," and other steamers, and are making at present other extensive applications. The "Allan" Line ventured in 1888 on their first ap-

plication of the system, and the same year the "Clan" Line applied it to two steamers. Since then the "Allan" Line have refitted other three of their steamers and built three new steamers, all of which have the writer's system; while the "Clan" Line have already refitted with new boilers, etc., 15 steamers and built 6 new steamers, making 21 already fitted with this system, while several other steamers are in course of being refitted, so that very shortly this company alone will have 30 or more steamers working with it. Other first-class companies are falling into line. The largest and most important British company, the Peninsular and Oriental Steam Navigation Co., notwithstanding their conservative tendencies, have now adopted it for their newest and fastest mail steamers, three of which are already running, and their new steamer now being built, the largest and fastest of all, which will approach in speed the fast Atlantic mail-steamers, is also having the writer's system.

The total result is, that since the start described as having been made in 1886 after about two years' continuous running of the "New York City," at this date there are close on 200 steamers fitted with the writer's system, many of them among the largest steamships afloat, and very few being of the smaller class of steamer.

It may be of sufficient interest historically to note that though there was not the slightest appearance of any applications of forced draught to mercantile steamers throughout the United Kingdom or elsewhere when the writer read his first paper on the subject at the Institution of Naval Architects in 1884, shortly after that period, and especially in 1886 and 1887, many inventors in this line stepped into the field, and for a year or two were much in evidence. These inventions were chiefly the original plan of Mr. E. A. Stevens' cold air blown into an ash-pit. One improvement on this plan, which formed the subject of a patent, consisted in merely laying the fire-bars across instead of lengthwise in the furnace, and having the spaces between the bars less than usual.

Some had jets of steam drawing in currents of air to the ash-pit; others had air-jets instead of steam for the same purpose ejected at considerable pressure by special pumping-engines.

Some of these plans were tried, but as they were found as

a rule to reduce the power of the boilers, and were besides less economical and more troublesome than natural-draught working, they soon fell into disuse, and the writer is not aware that any of them exist at this day.

The writer may be pardoned for referring more particularly to one of these cases, it being certainly one of the boldest attempts at appropriation on record, and not without its ludicrous aspects.

When the writer read his first paper on this subject at the Institution of Naval Architects in 1884, among the audience was an engineer superintendent for a firm of East Coast steamship owners, who then heard for the first time of a system of forced draught, applicable to steamships, other than the closed stoke-hold system. This engineer some five months afterwards got up a clumsy copy of the writer's furnace fronts and air-valves which, with some sheet-iron for a reservoir round the furnaces, were attached to the front end of a boiler with four furnaces in a steamer named the "Marmora" belonging to the firm referred to. This was done in September and October of 1884, and as the fixing up of the apparatus with a fan did not occupy many days, the steamer, it is said, was able to work itself a few miles northward to the Tyne for loading early in October, 1884.

The writer only became aware of this application in 1886, when the stir about forced draught began, and a paper, was read at the North-East Coast Institution of Engineers and Shipbuilders at Newcastle on the subject. Among the speakers at the discussion of this paper was the engineer referred to, who showed a drawing of the boiler of the "Marmora" and the apparatus he had fitted as a plan of his own. The character of the results obtained may be guessed when the power claimed as being obtained in the steamer by what he termed "forced draught" was about two thirds that obtained by natural draught from boilers of the size, and the average speed attained by the steamer 7.4 knots per hour.

The writer after seeing this drawing wrote both to the engineer and the firm owning the steamer, pointing out that the apparatus used was an infringement of his patent. The replies to these and other letters were to the effect that it was not understood at the time of application that the writer had a patent, and further, that the steamer had been totally lost

after several months' running, and nothing further of the kind had been attempted. The writer consequently allowed the matter to drop, but the activity of this new operator in forced draught was not yet at an end. At these discussions at Newcastle, Mr. Foley, a member of the Institution, showed a plan for admitting air from a fan through a hole in the backwater-space of a single-ended boiler into the combustion-chamber and ash-pit.

Fully two years afterwards, in 1888, a paper on "Forced Draught" was read at the Institution of Naval Architects by the engineer who had used, though in a most ineffectual way, the writer's plans, without asking leave, in 1884. The paper turned out to be an account of the application of a new patent system of the reader to a number of steamers belonging to the same firm of steamship owners, with numerous tables of results. To the surprise of the writer, this new system was simply that of blowing cold air into the ash-pits, with a small pipe leading a portion from the fan into the combustion-chamber through a hole in the backwater-space of the boiler, as proposed by Mr. Foley at the Newcastle meeting of 1886.

The defunct "Marmora" again figured in the paper as one of the reader's cases of "forced draught." A further noticeable matter was that in all the new cases given the I.H.P. produced by the boilers was, as in the "Marmora," greatly below ordinary natural-draught power. This circumstance was, however, little noticed in these days. At that time if a boiler simply raised steam by air supplied by a fan it was claimed as a case of forced draught.

Carried away doubtless by these original exploits, this engineer went on in his paper to throw suspicion on the writer's claim "that the 'New York City' was the first vessel that had ever used forced draught successfully as a normal condition of working in a sea-going steamer," and suggested that he himself, in the "crib" of the "Marmora," was the true claimant to this honor.

This claimant posed for some considerable time as an expert in forced draught on the strength of these assumptions and the fact that the steamers of the firm referred to were able to run at two-thirds natural-draught power with fan air-supply. It was only in the steamers under his own control that this make-believe forced draught was ever used. The

writer understands that one or two local steamship owners were induced to try it, but found that in working up to an ordinary power the results were so unsatisfactory that the apparatus was put ashore, and it became rather risky for a long time afterwards to mention "forced draught" to these owners. The *modus operandi* by which a boiler can be run with such apparatus at a low power without being wasteful is to reduce the fire-bars to one half, or less, of the usual length, restrict very carefully the amount of air entering the ash-pit, shut the funnel damper almost close, to prevent the heat from escaping up the chimney, and, at a large sacrifice of power, waste of fuel, for the power given may be greatly prevented. It would of course be much better to have no fan or apparatus when by one half the attention more economy and a greater power would be obtained by natural draught.

Returning to practical matters, the writer desires now to show more particularly, as promised, the causes which led to the disuse of the earlier modes of forced draught. It may be taken as an absolute rule that no real improvement in mechanism, or in a system of working in connection with processes or operations which continue in every-day use, is ever abandoned unless for some greater improvement, if left to the influence of unfettered competition.

The causes which led to the disuse of the closed ash-pit system of Mr. E. A. Stevens the writer has already, he believes, stated at sufficient length, in his description of the difficulties he himself encountered in his trial of that system in 1862, so that it will be unnecessary to add to the explanations there given.

The second design of the brothers Stevens in working boilers by fan-power instead of chimney-draught was that of using the suction of the fan to exhaust the base of the funnel and draw in the air rapidly through the furnaces—to fulfil, in short, the effect of the blast-pipe on the fire of a locomotive boiler. This system obviated several of the objections of the closed ash-pit, but it was found to have its own drawbacks. The merits and demerits of this system are concisely stated in the description given of this mode of working furnaces by the writer in his paper read at the Institution of Naval Architects in 1884, as follows: "A second method resorted to for increasing combustion in boiler-furnaces is that of exhausting

the air in the chimney or uptake by a fan, thus reducing the pressure in the flues or tubes and furnaces and thereby producing a more rapid current of air through the furnaces both below and above the grate-bars. This plan, so far as the supply of air to the furnaces is concerned, is in practice more workable than the plan previously described (the closed ash-pit), as the air enters the furnace not only at a greater velocity than is attainable by natural draught and is thereby capable of being more thoroughly intermingled with the fuel all over the furnace, but, being also balanced in pressure above and below the grate-bars, the operations of the furnace become much more easily managed.

"This mode of creating these advantageous conditions in the furnace is, however, objectionable. The passing of the hot gases of combustion through a working fan is, of itself, a mistake practically and theoretically.

"Even if it were possible for the machine to continue in working order, under this ordeal, for any length of time, the hot gases, if leaving the boiler at no more than 491° above the entering temperature,* would be twice the volume of the air which entered the furnace from the stoke-hold. A fan to exhaust the hot air would, therefore, require to be at least double the capacity of one which would have supplied the same quantity direct from the stoke-hold to the furnace. This plan, one of the earliest tried, is, therefore, impracticable for large boilers, and has only been occasionally used in boilers of limited size."

As the use of this as well of the other systems of forced draught designed by the brothers Stevens has only come to the knowledge of the writer since beginning this paper, it is satisfactory to find the above opinions confirmed by the reasons given by the Messrs. Stevens for their abandonment of this system very shortly after testing it in actual work.

It is remarkable that during the last twelve months there has been a resuscitation of this system with certain improvements which not only minimize the difficulties as stated, but add to the advantages of the system. These are now being tried on a scale with every advantage which skill, attention, money, and special opportunities can give.

This improved form of suction draught originated with

* That is, if entering temperature was 32° Fahr.

Messrs. John Brown & Co. of Sheffield in their desire to extend the use of that excellent heat-conductor, the "Serve" tube. This tube is better suited for effective forced draught than for natural draught, and the company having erected at their works two marine boilers having two furnaces each of 2′ 10½″ diameter with a fan to each boiler of sufficient size to exhaust the chimney, as in the second design of Messrs. Stevens, they were able to generate a considerable power and show that the boiler fitted with the "Serve" tube was much more economical than the boiler fitted with an equal number and diameter of plain tubes.

Messrs. John Brown & Co. having erected, two years ago, three similar marine boilers in their works with the writer's system of forced draught, they found by experience a large economical gain arising from the utilization of the heat of the waste gases in this system, both with the "Serve" and with the plain tubes. It occurred to them that if the arrangement of the writer's mode of utilizing the heat of the waste gases was united with the system of exhausting the funnel, a very good and economical system of forced draught would be the result. This reasoning was perfectly sound; for if the temperature of the fire-gases, with a high rate of combustion, were to be reduced from say 700° or 800° to 350° or 400° before entering the fan, not only would the fan dimensions be much reduced for a given power, but the heat utilized would give an equivalent value in fuel saved.

These are important advantages which go far to remove the otherwise insuperable disadvantages of this system, especially on board ship. There is, however, the other side of the question, the debit side, which the writer is convinced has not, in the conception and carrying out of this scheme, been sufficiently taken into account. What has to be paid to gain these advantages? In answering this question the following practical and scientific points have to be taken into account.

First, as regards the temperature of the gases acted on by the fan. It would be necessary to reduce the temperature to at least 400° before entering the fan to keep it within usable dimensions on board a ship. The next question—what surface of the air-heating tubes is necessary to reduce the temperature of the fire-gases to 400° for a given rate of combustion?—can be fairly calculated from the published results

obtained by Messrs. John Brown & Co. in their experimental boiler at Sheffield.

The following are the details of a seven hours' trial made at Sheffield on January 4th last on a boiler 10′ 6″ diameter × 10′ 6″ long, having two furnaces each 2′ 10½″ inside diameter; fire-grate area 32 sq. ft.; heating surface of boiler 911 sq. ft.; heating surface in 118 "Serve" tubes 3¼″ diameter and 7′ 6″ long, 741 sq. ft.:

Horizontal tubes for cooling fire-gases, 80 in number, 14′ 4½″ long, 3″ diameter; surface area, 913 sq. ft. Coal burnt per square foot of fire-grate per hour, 44.26 lbs. Temperature of the air of combustion entering the tubes for cooling the fire-gases, 50° F. Temperature of this air entering through the valves into the furnaces, 232°. Heat abstracted from the fire-gases in cooling tubes, 182°. Temperature of fire-gases in smoke-box before entering cooling tubes not accurately ascertained, but above temperature of molten lead and estimated at 650°. Temperature of fire-gases entering fan, 415°. Estimated degrees of heat lost by the fire-gases in passing from the smoke-box to the fan, 235°. Units of heat lost in the waste gases entering the fan, taking the air of combustion at 24 lbs. per pound of fuel, which the writer believes is likely to be under the actual quantity used in these trials, will therefore be

$44.26 \times 32 = 1416.32$ lbs. consumed per hour.

$(1416.32 \times 24) + 1416.32 = 35408$ lbs. of waste gases passing through fan per hour.

$35408 \times (415 - 50) \times .242 = 3{,}127{,}588$ units of heat lost in waste gases per hour.

In calculating the saving of heat on this trial, which, without the air-heating and fire-gas-cooling apparatus, would have been lost, the weight of air passing through the, air-heating tubes has to be ascertained. As a certain portion of the air of combustion is in this system, as worked by Messrs. John Brown & Co., drawn into the ash-pit from the stoke-hold, and as this quantity can only be guessed at, it will probably be sufficiently correct to estimate the quantity of air of combustion passing through the air-heating tubes at 20 lbs. per pound of coal consumed, which leaves 4 lbs. per pound of fuel as the quantity of air passing into the ash-pits. The heat

saving will, therefore, be as follows: $1416.32 \times 20 \times 182 \times .242 = 1,247,608$ units of heat.

This quantity of heat saved, it will be observed, is very much less than the quantity lost by the fire-gases in their passage from the smoke-box to the fan, and which should be presumably taken up by the cooling air passing to the furnaces through the tubes. The units of heat, however, which are actually lost between the smoke-box and the fan, according to the data given and explained above, are: $35408 \times 235 \times .242 = 2,013,653$ units of heat lost in waste gases between smoke-box and fan.

This shows the large proportion of 766,045 or 38 per cent of the total loss of heat between the smoke-box and the fan not accounted for by the effect of the air-cooling tubes. It is important to discover what became of this great quantity of heat unaccounted for. There can be little difficulty in accounting for it in this case. The boiler being placed in an open shed exposed to the atmosphere in cold weather, no doubt radiated this heat from the very large and highly-heated surfaces exposed to the atmosphere. The result is quite in keeping with experience of the loss of heat under such circumstances.

These conditions greatly helped the fan and added to its apparent effectiveness. The difference in effect, however, would be very marked if the boiler had been worked on board a ship under the usual conditions. An equal radiation of heat would have made the fan unworkable there, but doubtless when such apparatus is placed on board ship the surfaces will be much better protected from radiation, and special means will be taken to render the fan-rooms over the boilers of a temperature endurable by the attendants. But under the very best circumstances the heat over the boilers and around the fans on board a ship, with this system of working, must always be great and the temperature of the cooling air, instead of being only 50° F., will doubtless be something like 150°, if not more. The effect of this increase of temperature in reducing the power of the cooling apparatus will be very marked, so that the fan on board ship must be much increased in size and efficiency to effect the same combustion as obtained at the Sheffield trial.

A very striking feature of that trial is the low efficiency of

the air-heating or heat-extracting apparatus on the boiler. With an apparatus having a cooling surface in tubes 1.218 times that of the total surface of the boiler-tubes, and with the additional cooling power of the large surface exposed to the cold atmosphere, and the air entering the cooling tubes so low as 50° temperature, only the small addition of 182° to this temperature was utilized by a quantity of air less than that of the whole air of combustion. It is evident from these results that some very decided improvement must be made on this apparatus as tried at Sheffield before it is suitable for being used on board ship.

The amount of fan-power required for this system and the efficiency of its air heating apparatus, compared with the fan-power and efficiency of the air-heating apparatus of the writer's system, may be shown as follows: If the evaporative power of the light, quick-burning Yorkshire coal used at the Sheffield trial be taken at 1.8 lbs. per I.H.P. per hour with triple-expansion engines and 160 lbs. pressure, the rate of combustion would give 24.5 I.H.P. per square foot of fire-grate on the 32 sq. ft. of grate, and the total I.H.P. would be 784. This I.H.P. per square foot is very nearly the same as is obtained in the "Indiana" and sister-ships at sea at full power, and on 56.5 sq. ft. grate would give 1384.25 I.H.P.

In the "Indiana" the total surface in the air-heating tubes is only .206 that of the surface area of the boiler-tubes, or about one sixth of the proportion of the air-heating apparatus of the Sheffield boiler. The temperature of the fire-gases leaving the air-heater of the "Indiana's" boiler on board ship, notwithstanding its limited area of tube surface, would, while making equal power, not be much different from that of the fire-gases entering the fan at the trial of the Sheffield boiler. The air-heater of the "Indiana" is, moreover, not nearly so effective as the heaters now used by the writer.

It would be safe to say that with air-heating tube surface of .4 of the boiler-tube surface the temperature of the escaping fire-gases would, with the writer's system as now applied, be under 390°, while the heat imparted to the whole air of combustion would not be under 230°.

The power required to drive the fan at the Sheffield trial the writer understands to have been 30 I.H.P. On board ship the power would require to be much greater. With fans of

large diameter, if such could be admitted on board ship, the proportion of fan-power to evaporative power could, however, be considerably reduced, but, under the most favorable circumstances conceivable, the fan-power required for equal evaporative power of boilers would be on this system at least four times that required for the system of the writer. With a belt-driven fan the writer has obtained fully 2000 I.H.P. at a high rate of combustion from boilers on board ship with 8 to 10 I.H.P. expended by fan-engine. It is evident, therefore, that this system of the suction draught cannot, even under the very best conditions in which it could be placed on board ship, at a high rate of combustion, approach the system of the writer in efficiency or economy.

In working this system it is necessary that there should be one fan at least for each end of every boiler. When there are several furnaces in each boiler-end, if the fire-door is opened the fan of the power required for the number of furnaces will necessarily pull from the point of least resistance, which is the open furnace-door. This will cause a very strong draught of air through the open furnace, and for the time that the door is open the draught through the other furnaces will be reduced, while the combustion-chamber and tubes of furnace having its door opened will be rapidly cooled, and will, in due time, injure the tube-ends if some means of shutting off the furnace being operated on is not adopted. It is true that the heated air will to some extent be drawn in at the same time from the side valves. This may, however, be insufficient to save the tube ends, if the shutting off of the furnace, which is a troublesome operation, is not adopted.

A very singular advantage has been claimed by its promoters for this system, which they term *induced* draught, distinguishing it from what they term *forced* draught. The term "induced" draught, the writer considers, can only properly be applied to a draught carried, or led in, by the agency of a current or force moving in the same direction, as in a Gifford injector.

The popular term "suction" appears to the writer to be the proper distinguishing name for the system of draught adopted by Messrs. John Brown & Co. What they claim is that "with *forced* draught the flame and hot gases are forced under pressure upon the tube-plates and tube-ends, and must

get through as best they can; with the *induced* draught the gases practically do not touch the tube-plates and tube-ends, because a considerable vacuum at the smoke-box end of the tube sucks the gases in the combustion-chamber like so many steady streams into the tube-mouths."

The idea evidently embodied in this claim and description is that it is a bad thing for the heat of the furnace to impinge or act on the tube-plates and tube-ends or other part of the heating surface, and that in this suction draught the hot gases, somewhere after passing the bridge of the furnace, separate themselves into round, flexible currents, equal to the number of the tubes, and somewhat less in size than their inside diameter, into which they individually enter without collision or without ever touching a tube-corner or the tube-plate. But as heat must affect the colder plating by radiation if confined inside of a combustion-chamber, it is necessary, according to this theory, that these accommodating currents must surround themselves with a cold or non-radiating envelope so that the usual communication of heat, as in other boilers, may be prevented in the boilers where this draught is used, and the tubes-plates and tubes preserved by the considerate action of the fire-gases.

If such eccentricities on the part of the fire-gases, as is claimed on behalf of this system, should actually occur, it would be important to learn at what part of the boiler the heat withheld from the tube-ends and tube-plates is taken up by the heating surface. It can scarcely be inside the tubes, for the power of this fan-suction increases rapidly towards the smoke-box end, so that its effect in keeping the hot gases from being "forced under pressure upon the tube-plates and tube-ends" must, in a greater degree, prevent the hot gases from touching the surface of the tubes themselves, and thus shield them also through their length from the injurious effects of the heat. The dreaded heat according to this theory must therefore chiefly find its way into the fan and the chimney, as it has been shown that in the case of the Sheffield boiler it imparted very little to the air in the cooling tubes, even though horizontal.

This system is not, however, so bad as its promoters in their anxiety to add a safety feature to its action would have us to believe. It fortunately knocks about its heat very much

like other boilers, and the laws of nature are not suspended in favor of this system, either in this or any other point of its action.

The system which "forces" from a given weight of fuel burnt the greatest heat "under pressure upon tube-plates and tube-ends" is the system which, if it possesses no other bad feature, all users of steam-power should adopt, as it would prove the most economical and give the greatest power with the least trouble. The fact that the writer's system, which, according to Messrs. John Brown & Co.'s circular, acts in this objectionable manner, has been so acting for the last nine years in some boilers, and in many hundreds of boilers for a considerable number of years, yet has never injured a tube or tube-end, is sufficient evidence that Messrs. John Brown & Co. have been somewhat hasty in their judgment on this matter. In his concluding remarks on the closed stoke-hold system the writer will particularly refer to the real cause of the injury to the tube-plates and tube-ends so common in boilers worked by that system.

It has been already mentioned that Messrs. John Brown & Co.'s system is now being tried on a large scale under favorable auspices. This trial is in the boilers of the "Berlin" of the "American" Line, which, though not designed for, were fitted with, the writer's system in 1887. For several intelligible reasons these boilers as fitted have not given so much power for equal grate or heating surface as the other steamers belonging to the Company with the same system. The "Berlin" is therefore a favorable case in which to show improvement in power and efficiency. As the experience gained from the Sheffield boilers has been before the company since starting them, and having had the assistance of several skilled experts and the past experience of these boilers to guide them to every necessary improvement, this system if it can do well in any steamer has every chance to do well in this one. As fans can be made sufficient to give an exhaustion almost equal to a locomotive blast-pipe, a considerable increase of power at least should be obtainable. The writer is without any information as to the proportions of fan-power or surface of cooling tubes used or the extent of grate surface, but he is convinced that both the efficiency of fan-power and of the cooling surface must be considerably

better than in the Sheffield boilers or the results will be very unsatisfactory. The boilers have also now been fitted with "Serve" tubes which of themselves should give an increased steam-supply of 10 per cent from the same quantity of fuel formerly consumed. The air-heating surface in horizontal tubes will probably be also in this case about six times greater than the air heating tubes were with the writer's system. There should be therefore considerably better results in this steamer with all these additional improvements and expenditures, even though the efficiency of the system should actually be considerably less than in the one removed.

The writer has up to this date no particulars whatever of the results in this steamer, but time will show how far his estimates of the comparative efficiency of this system and his own are correct.

The last design of Mr. E. A. Stevens was that of the air-tight fire-room charged with air above atmospheric pressure, more generally known since its resuscitation and its extensive use in war ships in recent years as the "Closed Stokehold" System.

It has already been stated that the chief objections to this system are its injurious effects on the boilers and its wastefulness of fuel if used at a rate of combustion much above that of good natural draught.

In torpedo-boats with a single locomotive boiler, its dangers can, with certain precautions, be greatly minimized, as the form of furnace in this type of boiler much reduces the risk of injury. Ordinary marine boilers can be designed where, if the air-pressure used is not high, comparatively little injury would follow from the use of this system, but these boilers would not be suitable for war ships. In all boilers of whatever design if worked to a ratio of power on this system say beyond 1 I.H.P. for every two square feet of heating surface the wastefulness of fuel is large and the likelihood of injury increases. If the ratio of combustion extends still further, the wastefulness and risk of injury rapidly increases.

The result has been that in all war ships and cruisers fitted with boilers of the class suitable for these vessels when worked at rates of combustion exceeding that of natural draught the tubes in the combustion-chamber begin to leak

after a few hours' trial. These leakages are generally so bad that the boiler is rendered useless, fires have to be drawn, and the tubes made tight before the boiler is again workable. These leakages also occur with this system in war-ship boilers even at low rates of combustion, and much has been said and written in trying to account for this serious defect of the system.

In his papers of 1884 and 1886 read at the Institution of Naval Architects the writer gave his explanation of the cause and predicted the serious consequences which would occur in navy boilers if the system was continued, before one hundredth part of the damages which have since occurred had taken place.

The writer will explain in detail how the injury to the tubes and tube-plates occurs, with the conditions and sequence of effects, in order that the matter may be more fully understood.

In a boiler worked on this system at a given evaporative power the temperature in the interior will at periods be higher than in a similar boiler with equal evaporation not worked on this system, because at the periods of firing and cleaning fires the temperature is much lower than in the other boiler.

When a rapid combustion takes place in boilers with "closed stoke-hold" forced draught, especially in navy boilers, which have more contracted spaces than are usual in mercantile steamers, there is necessarily a high temperature in the furnaces and combustion-chambers. The tube-ends for the following reasons must be higher in temperature than any other part of the combustion-chamber: Not being homogeneous with the tube-plate, the tube-ends in contact with them cannot transmit the common heat of the chamber so rapidly to the water as they would do if in molecular union with the tube-plates. The heat of any part of the metallic surface communicating the heat of the fire-gases to the water depends more on the rapidity with which the heat passes to the water, than on the temperature of the fire-gases themselves, as in the hottest part of the furnace the plates overhead are comparatively cool so long as the evaporation is unimpeded. The heat taken up by the tube-ends in contact with the tube-plate, the writer believes, reaches the water only to a small extent through the tube-plate, but chiefly by lateral conduction to

and through the part of the tube in contact with the water. As the surface of each tube inside the tube-plate has to transmit the heat it receives from the hot gases in contact with its own area, and also the greater part of the heat taken up by the area of the tube embraced by the tube-plate, it is evident that this can only be accomplished by the end of the tube being considerably hotter than the part inside clear of the tube-plate. The very hottest part of the tube must certainly be the extreme end inside the combustion-chamber. Doubtless all overlapping plates and rivets, for the same reasons, attain a higher temperature than the single plating, and consequently they are also sometimes damaged by the inrush of cold air, but owing to their thickness they are much less sensitive under a rapid change of temperature, as they cannot be cooled suddenly.

Though the combustion-chamber and tube-ends of a boiler worked with a closed stoke-hold attain a high temperature with a rapid combustion, no damage would arise from that temperature if maintained uniformly or without great variations.

In locomotive boilers it is found that the tube-plates and tube-ends are not damaged with much higher temperatures than can be found in any combustion-chamber of a marine boiler under the very highest forced draught. Fortunately there is no sudden change in the locomotive boiler by impact of cold air on the tube-plate either in running or standing. When steam is shut off the action of the blast-pipe is suspended, so that when the engine is stopped there is no inward draught, though the fire-door is open, and the fire-box continues subject to the glow of the incandescent fuel.

These saving conditions are absent in the closed stoke-hold system of working. When the combustion-chamber and tube-ends have been highly heated by the rapid burning of a heavy charge of fuel, though no harm is done so long as the furnace-door is shut, as soon as it is opened the conditions immediately change. If the fire is not well burned down and is very hot, the first rush of air is rendered comparatively innocuous by being rapidly expanded and reduced in velocity by the great heat of the furnace.

This conservative action of the hot furnace is, however, rapidly overcome by the continuous rush of cold air accu-

mulating in density and velocity as the furnace cools down, and eventually reaches the tubes and tube-plate before they have had time to cool down, at a temperature it may be 800° or 1000° less than that of the hot gases, which not many seconds before had been in contact with them.

The iron or steel tubes and tube-plates, it must be noticed, do not cool very rapidly after being highly heated, more especially when surrounded by a temperature considerably higher than themselves. When the cold current reaches the tube-plates the thin tubes with their hot ends being much more quickly affected by the change of temperature than the thick tube-plates, shrink suddenly and cause the inevitable leakage which has proved so disastrous in the boilers of war ships worked by this system.

It is not likely every time that a furnace-door is opened for stoking that the cold air reaches the tube-plate with the effect of causing the tubes to shrink suddenly, as, it may be, the cooling down is often sufficiently gradual, owing to the conditions of the furnace and the short period the door is opened. It is also very probable that the tubes are loosened, not by one or two shrinkages, but by a succession of shrinkages, like jars caused by the blows of a hammer. The leakage is, however, inevitable after a certain short period of working, and the writer is not aware that any war ship has ever been worked continuously for even a few days at a power equal to that of a good natural draught without being more or less injured. This injury also not unfrequently occurs with this system, even when working at a low power in some boilers. This apparent anomaly appears to the writer to be explained in this way: The occurrence generally takes place after the boilers have been under steam for some days. During the period of working the water in the boilers loses its original purity, and gets a trifle salt and a little greasy. This condition raises the temperature more or less of all the parts in contact with the fire-gases. The combustion, though not so rapid, yet raises the temperature of the plating considerably, and if a fire be burned low under these circumstances, the cold air, still under considerable pressure, will much more quickly find its way to the tube-plates at the difference in temperature sufficient to cause shrinkage of the tube-ends.

It should also be noted that with a closed stoke-hold there

must always be an air-pressure above the atmosphere; and though the admission to the furnaces may be restricted, the velocity with which the cold air rushes into the furnace when a furnace door is opened is not that due to the positive pressure only, but to that of the positive pressure of the stoke-hold combined with the minus pressure of the furnace due to the chimney, which, with only one eighth of an inch positive pressure, may create a velocity of current in some boilers of 30 to 40 feet per second.

The phenomena thus described, the writer believes, more or less correctly explain what actually takes place in producing leaky tubes in boilers worked with closed stoke-holds.

It should be mentioned that a protection for the tube-ends has lately been introduced in the British Navy. This is a long thin iron ferrule inserted into the tubes in the combustion-chamber, having a capped flange which covers the ends of the tubes. This ferrule will no doubt protect the tube-ends from the effect of the cold air while it lasts, but its lifetime can only be one or two days under full power, and probably ten or twelve days under reduced power. It will often prove a treacherous friend by giving out the moment when its services are most wanted. It is clear that such a protection can never insure safety in circumstances requiring the vessels to remain under steam for many days, or for working at a high power for any lengthened period of hours.

The other chief defect of this system is that of its wastefulness of fuel when worked at a high rate of combustion. This wastefulness is most noticeable in boilers of war ships, where the reduced dimensions and heating surface per I.H.P. bring the wasteful conditions more quickly into play. The greater the rate of combustion, as has been explained, the greater is the percentage of air required per unit of fuel. The velocity of the fire-gases through the furnaces, combustion-chambers, and tubes is correspondingly increased, making the heating surface less effective. There is consequently a great increase in the temperature and volume of the waste gases leaving the boiler, and the actual proportion of the total heat of combustion utilized for evaporation may thus be less than one half, as has been already illustrated.

It will show how much the quantity of air required for combustion per unit of fuel and the high temperature of the

waste gases under a high rate of combustion affect wastefulness, or economy, *by their effect on the heating surface of the boiler rendering it more or less effective per unit of coal consumed.*

Take, as an illustration, a navy boiler on a four hours' Admiralty trial, burning 2.6 lbs. of coal per I.H.P., *and the same boiler* on the writer's system giving the same aggregate power from *the same engines* with a consumption of 1.6 lbs. per I.H.P., the respective consumptions being fair approximations of actual practice. Call the closed stoke-hold boiler No. 1 and the one on the writer's system No. 2. Assume the rate of combustion in both cases to give 20 I.H.P. per square foot of fire grate. The respective weights of coal consumed will be, No. 1, 52 lbs. per hour, and No. 2, 32 lbs. Assume, further, that the tube heating surface of the boiler is 1.6 sq. ft. per I.H.P. and the area through the tubes 1.25 sq. in. The weight of the air of combustion in such a trial the writer believes will be found in No. 1 to be at least 30 lbs. per pound of coal consumed and 20 lbs. in No. 2, while the average temperature of the escaping gases would be 960° in No. 1 and 400° in No. 2, the surface area of air-heater in the latter being, say, .35 of the boiler-tubes. The calculation of the average temperature of the fire-gases passing through the boiler-tubes is taken in No. 1 at 1250°, and in No. 2 at 1000°.

The volumes of fire-gases at these temperatures, taking their specific volumes as equal to air, are, respectively, 42.86 and 36.71 cu. ft. per lb.

These data give the following results:

No. 1.

$(2.6 \times 30) + 2.6 = 80.6$ lbs. resultant gases per I.H.P.

$80.6 \times 42.86 = 3454.5$ cu. ft. of fire-gases per I.H.P. per hour.

3454.5 cu. ft. per hour = 1658.18 cu. in. of fire-gases per second passing through an area of 1.25 sq. in.

$\therefore \dfrac{1658.18}{1.25 \times 12} = 110.54$ velocity of fire-gases through tubes in feet per second.

No. 2.

$(1.6 \times 20) + 1.6 = 33.6$ lbs. resultant gases per I.H.P.

$33.6 \times 36.71 = 1233.45$ cu. ft. of fire-gases per I.H.P. per hour.

1233.45 cu. ft. per hour = 592 cu. in. per second of fire-gases.

$\therefore \dfrac{592}{1.25 \times 12} = 39.47$ velocity of fire-gases through tubes in feet per second.

It is obvious that from the much greater quantity of fire-gases (2.8 times) which pass through the tubes of No. 1 boiler in a given time, a considerably less quantity of heat per pound will be utilized by this boiler during the passage of the gases than will be utilized per pound by No. 2 boiler from the much slower movement of the gases through it.

Thus the greater wastefulness of No. 1 boiler is explained not only by a comparison of the units of heat lost in the waste gases, as has been done in an earlier part of the paper, but also by comparing the greater and less velocities of the volumes of the hot gases in the two boilers passing over a given surface in a given time.

It might, however, be questioned here: If the fire-gases are maintained at a higher temperature in the tubes in No. 1 boiler than in No. 2, the former should evaporate more in a given time, that is, supply steam for a greater power. It would certainly do so if other things were equal; but, as has been shown, the working conditions are very unequal. The amount of evaporation is determined by the actual units of heat received by the water of the boiler in a given time. It is evident that fire-gases passing through tubes are more unequal in temperature at a high velocity than at a low velocity. The outside gases next the surface of the tube will be considerably cooler than the inside core, and in this way the proper evaporative effect due to the average temperature is impaired.

It is also certain that the velocity of the gases in the central part of the tube will be greater than the outside envelope, which is retarded by its contact with the inside surface of the tube. This inequality of velocity will become all the greater as the velocity is increased. It therefore follows that the *mean* of the average temperatures of the gases in the smoke-box and that of the gases entering the tubes from the combustion-chamber does not correctly represent the effective temperature in contact with the tube-surface.

It may be taken generally as a fact, that when evaporating equal quantities of water in a similar boiler the *average* temperature in *the furnaces*, though not in the tubes, is higher with

the writer's system than with the closed stoke-hold or in any system with cold-air supply. The cause of this has already been explained when describing the effect of the supply of hot air for combustion.

The maximum temperatures of the other systems for equal evaporation are considerably higher to compensate for the much lower temperature to which the furnaces and interior parts of the boiler are brought by the scour of cold air to which they are subjected when the furnace-doors are open.

These endeavors to show by well-known principles and plain figures the causes which affect economy and wastefulness in boilers are well sustained by facts. It is within the experience of many, that with boilers on the closed stoke-hold system, worked at a rate of combustion as high as will produce a steam supply to triple-expansion engines of 20 I.H.P. per square foot of fire-grate of ordinary size, a consumption of 2.6 lbs. of fuel per I.H.P. per hour, and in some cases even more, is required.

It is also well known to many that with the writer's system 20 I.H.P. per square foot can be obtained on a fire-grate of ordinary size on very much less than 1.6 lbs. per I.H.P. per hour.

The expenditure of 1.6 lbs. has been assumed here to meet the case of the supposed more wasteful engines of war ships and cruisers when working at a power requiring as much as 20 I.H.P. per square foot of fire-grate of their boilers.

In bringing this paper to a conclusion the writer has to plead in extenuation of its length and diffusiveness the fact that it has been written at odd hours, and at considerable intervals, as the exigencies of his business permitted. He has endeavored to cover most, if not all, of the ground occupied by the different modes in which forced draught has been attempted, and to point out in the plainest manner and with the simplest possible calculations the principles and natural laws which govern and determine the effects of the use of air-pressure in combustion of fuel in furnaces. The writer trusts that his unelaborated attempts to show these principles will make this important subject better understood, and that his contribution to this great historical congress may not be altogether valueless.

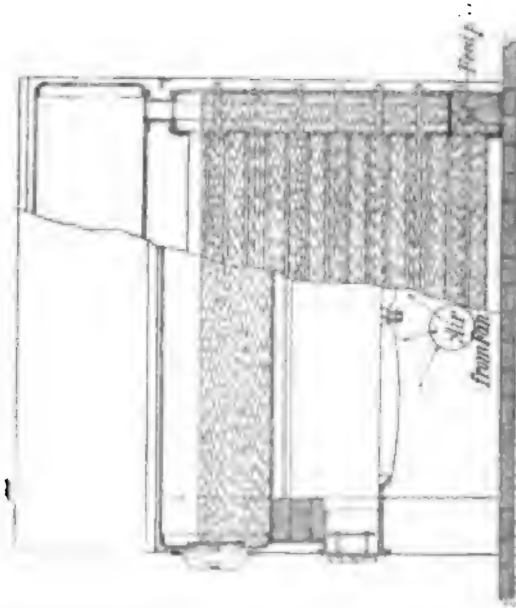


Fig. 2

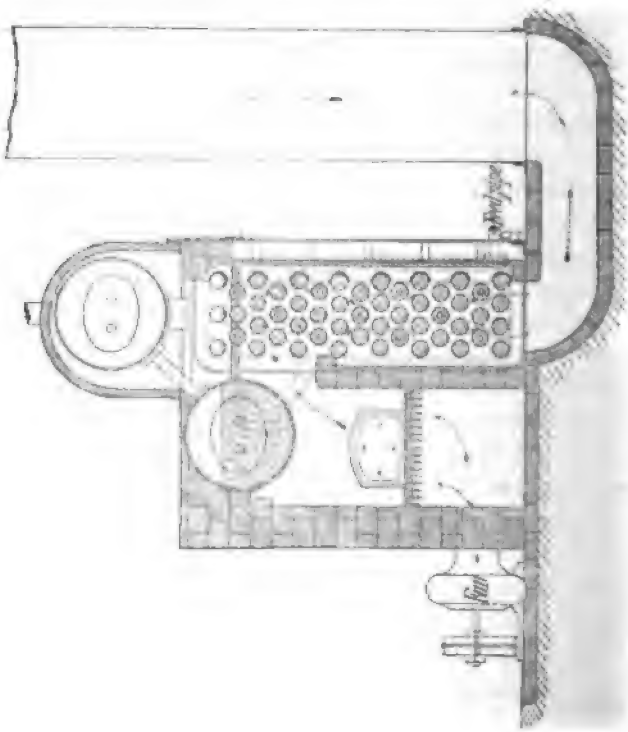


Fig. 1

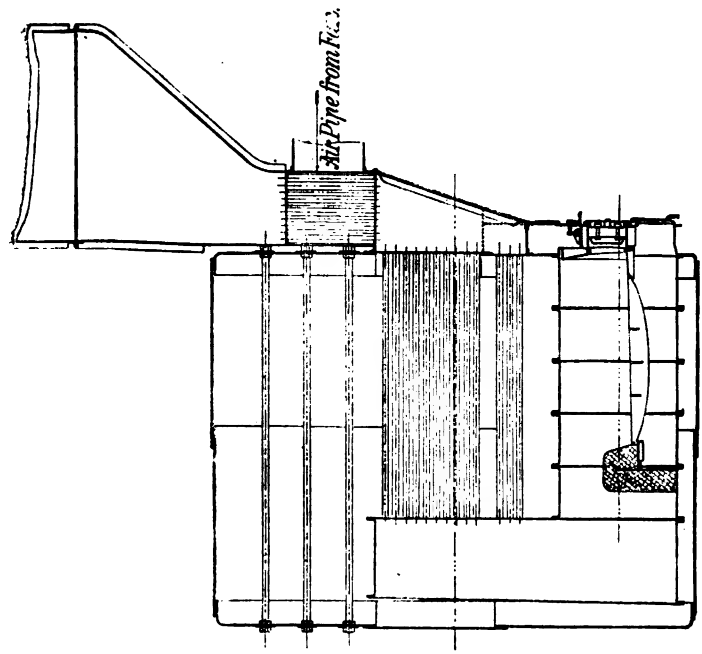


Fig 4

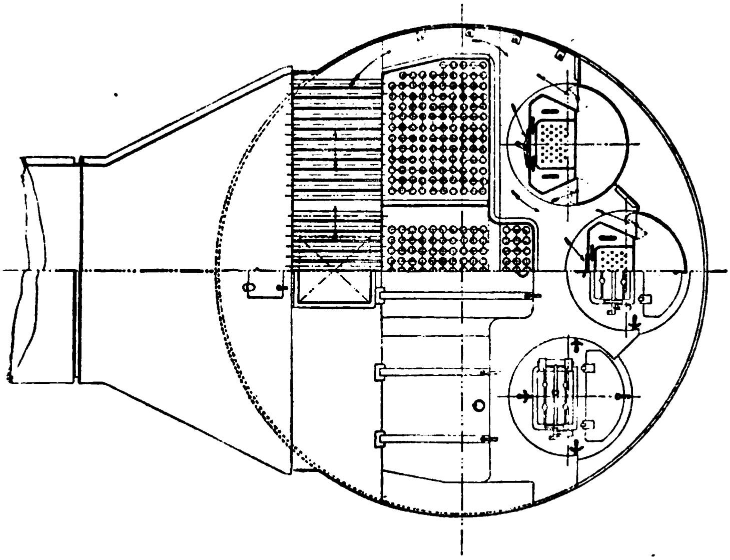


Fig 3

to softness, and exhibited signs of bulging between the screwed stays,—yet in all these years not the slightest leakage at seams, rivets, or tube-ends ever occurred. This fact is in striking contrast to the damage to the interior of the boilers in war ships, from the use of the closed stoke-hold system of forced draught, with a much lower rate of combustion, and after only short periods of working with fresh water in the boilers.

Notwithstanding the very interesting applications of forced draught in the early days of steam-navigation, first in this country, and shortly thereafter elsewhere, — the honor of designing and introducing which undoubtedly belongs to Mr. Edwin A. Stevens,—this steamer, the "New York City," the writer claims to have been the first sea-going or ocean steamer ever fitted with actual forced draught, or that ever worked continuously at sea with forced draught. The writer trusts that, in view of the actual facts, he will be pardoned in further stating his belief that until the sailing of the "New York City" no system of forced draught which had been previously tried was capable of maintaining, above natural-draught rates, complete combustion with economy and safety to the boilers, or with combustion under proper control and arrangements suited to give favorable working conditions to the stokers.

After the "New York City" had continued running uninterruptedly for a year in the successful manner stated, her performances began to attract the attention of some steamship owners who had obtained particulars of results from Messrs. Scrutton, Sons & Co. These were, however, deterred for some period from refitting their steamers with new boilers on this system, by the offered advice and warnings of many engineers in prominent positions, who, with superior foresight, predicted an early and disastrous collapse of this forced draught and the boiler of the "New York City." As the boiler most inconsiderately treated these predictions with open disrespect by continuing to work most satisfactorily voyage after voyage under the trying conditions described, some steamship owners at last plucked up courage and ordered new boilers on this system for their steamships. The first firm of importance to begin was Messrs. George Smith & Sons of the City Line of Calcutta steamers, who, in

the early part of the year 1886, contracted with the writer's firm to convert the compound engines of their steamer "City of Venice" into quadruple-expansion engines, having their steam from two forced-draught single-ended boilers 14′ 0″ diam. by 10′ 10″ long, and of 150 lbs. pressure, with 6 furnaces, instead of the four boilers previously used with 12 furnaces. The new engines were to work from 1600 to 1800 I.H.P. at sea as required, the power of the compound engines and boilers at sea having been 1300 I.H.P. This contract was successfully accomplished, the steamer being tried in January, 1887; and since that trial all other steamers of Messrs. George Smith & Sons which have been refitted, and every new steamer they have built, have been fitted with the writer's system of forced draught.

The writer desires to put on record events which occurred at this time, illustrating the fact that Americans are freer from the trammels of that conservatism which is founded largely on prejudices than are his own countrymen.

While the British steamship owners were dubiously looking at this new mode of greatly increasing the power of their steamships, which at the same time much reduced the rate of fuel consumption as well as the weight of the boilers and the space they occupied, the writer was visited in Glasgow in February, 1886, by Mr. James S. Doran, Superintendent Engineer of the "American" Line of steamships, who had been sent from Philadelphia for the purpose of inquiring into this matter of forced draught, reports of which had reached the President, Mr. C. A. Griscom, and the Directors of his Company.

The writer trusts he will be pardoned for taking this opportunity of expressing his opinion regarding this Company as one representative of the highest type of American enterprise and one to which the ship-building and engineering world owes much for the impulse they have given towards higher attainments, by their readiness to adopt improvements in order to keep in the front of the most advanced naval and engineering practice of the day.

As the "New York City" was about due in London at the time, and required to make a short run from thence to Cardiff for a cargo of coal, Mr. Doran was enabled, by making this short run, to see the forced draught in that steamer in oper-

ation. Had Mr. Doran listened to the reports of some engineers who had plenty to say on the subject but who knew little or nothing about it practically, he would doubtless have returned to America with an unfavorable report. Being, however, well able to judge of its value after having seen the system in operation, the issue was, that later in the same year his company contracted with the writer's firm for the complete refitting of their steamship "Ohio" with new engines and boilers designed by the writer, the boilers being fitted with his forced-draught system. This contract, which was undertaken with the guarantees of 2100 I.H.P. on a consumption of coal not exceeding 1.25 lbs. per hour on a lengthened trial, was satisfactorily accomplished on the completion of the refit of the steamer in June, 1887. The Company having during 1886 come into possession of the well-known Inman fleet, had likewise contracted towards the end of that year with Messrs. Laird Brothers of Birkenhead for the refitting of their steamer "City of Berlin," the boilers of which, though not built or arranged in this ship to the plans of the writer, were fitted by that firm with his system of forced draught.

After fully two years' experience of working the "Ohio" the Company contracted with the writer's firm in 1889 for the refitting of their steamer "Indiana," the particulars of which have already been given. Before the "Indiana" was completed in the latter part of 1890 the Company again contracted with the writer's firm for the converting of the steamship "City of Paris" from the closed stoke-hold system to his system of forced draught. This undertaking presented special difficulties in being carried out, as the arrangement of pipes and other fittings could only be partly altered to suit the new system, while the structural arrangements of the ship could not in any way be altered. One of the difficulties which was eventually found to render the fans much less effective than in ordinary installations or than the writer anticipated, was that, owing to arrangements of details which could not be altered except at great expense, the discharge passage from the fans on the main deck to the boilers below could not be made in a continuous pipe, but in alternatively larger and smaller portions with awkward connections to the air-heaters on the boilers. The effect of these passages was to dissipate considerably the power of the fans, while a deficiency in area

in one part of the boilers themselves very much reduced the power of combustion in the furnaces of that steamship. The causes of the reduced efficiency were not, however, apparent or easily discovered, being greatly masked by the indication of sufficient air-pressure in the ash-pits.

This was a unique case, and the writer learned much from the exceptional behavior of the boilers of this steamship, especially regarding the causes and conditions which limit the power of combustion under certain circumstances, though a considerable period elapsed before he found a complete solution of the apparent by anomalous results. At the end of the first season after the alteration to the writer's system, the air-passages from the air-heaters to the furnaces were somewhat enlarged. The combustion was increased by the greater weight of air passing through the fuel, though strangely the air-pressure was not thereby sensibly increased in the ash-pits. This phenomenon arose from the fact that when the air admitted by the valves to the ash-pits does not pass quickly through the fuel it rapidly increases in temperature, and also in pressure, so long as the cooler air in the reservoir above is of a higher pressure, which it invariably is. This air-pressure, which is caused by local increase of volume, consequently reduces the weight of air passing through the furnaces, and also the rate of combustion.

The combustion under such circumstances is still further reduced by the proportionately greater quantity of air entering over the fires tending to increase the pressure above, which, with the contracted area previously mentioned, hindered still further the passage of the air through the fuel below.

These were the circumstances which prevented the normal development of the forced-draught power in the "City of Paris," and which makes her as now fitted a much lower example of the writer's system than the "Indiana" and her sister ships belonging to the same Company. It must, however, be remembered that though thus handicapped this steamship has made the fastest passage on record to this date from Queenstown to New York, the time being 5 days 14 hours and 24 minutes on a passage of 2782 nautical miles, though the grate-bars are 13 inches shorter in length than when working with the closed stoke-hold, while the acting grate surface is

plete control over the combustion and evaporation under such conditions as those of a ferry-boat in a slip. Although, as I have already stated, we purposely design our boilers to stand a higher pressure than we need for working the engines, the pressure will at times exceed that for which the safety-valves are set, and then there is blowing off with considerable attendant waste.

MR. JOS. R. OLDHAM:—I think the very best way to feed a boiler is to introduce a warm feed, and the very worst possible way of firing a boiler is to allow cold air to get into the furnaces and strike the tube-plates.

I would like to ask Mr. Howden if it would not be as advantageous to raise the stack to a height corresponding with mechanically forced draught.

I understand that about ten feet in height of stack induces a draughtequal to about $\frac{1}{16}$ inch water-pressure; then 100 feet would give us a pressure equal to about $\frac{5}{8}$ inch of water. I would like to learn whether the refuse of the coal would not be burnt as well by that means as with his system of mechanically forced draught.

MR. A. H. RAYNAL:—Recently the question of forced draught became of great importance to me. When it became necessary for me to determine the proportions of the blowers for the "Bancroft." I was confronted with the difficulty that a very low air-pressure was conditioned—only half an inch of water. I was satisfied that the engines would produce the required power, provided the steam could be furnished by the boilers, which, as usual, were small. So, finally, everything depended on the question of how much fuel could be burned at the given pressure, and I found very conflicting data on the subject. It then occurred to me that I had experience in an analogous case, that is, in the working of foundry cupolas. In cupola practice it has been proven that not pressure but volume of air furnished produces best results; and applying this to the problem in hand, I argued that if a fan-blower is used, and a pressure is specified, then the circumferential velocity of the fan is determined, as also the diameter, because of the practical piston-speed of its engines. The volume is now proportionate to the face of the fan and the size of the discharge-opening. To suit all the required conditions of the fires there should be an adjustable opening, and the blowers of ample capacity for maximum performance.

Then by increasing or decreasing the discharge-openings of the blowers we obtain more or less volume of air at the fires, and more or less consumption of fuel; but this should not be done by increased or decreased speed of the fan, for this means more or less

pressure, and there can only be one effective pressure for given thickness and condition of fuel. And it must not be forgotten that it is the amount of discharge-opening which determines the power consumed by the fan as well as the volume of air furnished; that with discharge-openings closed no power is given or used except that of the friction of the fan in its envelope.

I therefore put in blowers about three times as large as would be put in under ordinary circumstances, and the results of the trials have proven that my theory is not far from correct; and looking over a great many figures given where pounds of fuel burned on various surfaces under equal pressures varied so materially, I believe that it has been due to different volumes of air furnished.

We used the closed ash-pit system, and at some trials found that providing additional openings for admission of air produced proportionate consumption of fuel; and I would like to call the special attention of engineers in future trials to giving greater volumes at reduced pressures.

MR. JOHN D. ELLIS (submitted in writing after the meeting): —Whilst Mr. Howden has ably explained the views he holds in accordance with the good results he has obtained from his own now well-known way of working out mechanically assisted draught, some of the opinions expressed with regard to at least one other system are being upset by actual experience. I acknowledge the good work done by his system for "moderate" rates of *forced* draught, but I hold that in marine boilers we are entering upon an era of much higher rates of combustion per square foot of grate, and that for such, exhausting the gases by suction will be found preferable to pushing the air through the boilers. To explain my views and the results already obtained, I cannot do better than to request the favor of your close attention to the paper, read at the last meeting of the Institution of Naval Architects, on the subject of experiments with the Ellis & Eaves suction draught.

On reflection the conclusion is unavoidable, that, having *high* rates of combustion in view, the more you push or force the air and gases through the boiler, the more you increase your difficulties and troubles, whilst you have a clear course if you exhaust the gases by suction. Mr. Howden makes merry at the view that the combustion-chamber tube-plate and the tube-ends are under more favorable conditions with a vacuum than with pressure; yet, as in Galileo's case, it is so. The explanation is, of course, not the one Mr. Howden attempts to foist upon the advocates of "exhausting" or "suction" draught in his endeavor to make them look ridiculous; yet incidentally he gives the true reason, viz., the

higher the vacuum the less contact there will be between the gases and the tube-plates and tube-ends, and therefore the less danger of overheating these. It is no exaggeration to say that with *forced* draught, i.e., with "pressure" in the combustion-chamber, the gases must find their way through the wall of the tube-plate as best they can (hence the overheating and susceptibility to rapid changes of temperature), whilst with a vacuum instead of pressure the gases are sucked in steady streams into the centre of the tube-ends, these by preference being beaded over as in American practice. It is not ridiculous to avoid the troubles of the past—of overheating the tube-plates and tube-ends or of caking them over with a deposit; and in my opinion it is a great gain that the tube-plate in this system ceases to be the "over-effective" heating-surface which it is under the old conditions of draught by pressure. That the gases will endeavor to pass through the centre of a plain tube in order to avoid friction is a matter of course, and the tendency is naturally still greater with a "Serve" tube. Bearing in mind that the first three inches or so of a "Serve" tube are without ribs, that consequently the section for the gases is greatest and friction least, what is more natural than that, helped by the considerable vacuum, the gases should flow to the centre of the tube-end. avoiding excessive heating at this important point, but giving up their heat later when they meet the ribs of the Serve tube, and the retarder put in the centre—and still later the air-heating tubes? Thus the gases are cooled down and harmless when they reach the fans, and the cooling down at the same time is converted into economy. The matter of economy is in a nut-shell. If you can burn 60 lbs. per square foot of grate in a given size of boiler, and the gases pass into the fans at the same temperature as they do into the funnel with natural draught burning 15 lbs. per square foot, the evaporation per pound of fuel must be very similar, and the advantage of reduced boiler space, weight, and first cost of installation well repays the extra cost of production by means of the exhausting-fans.

Mr. Howden imagines that greatly larger fans and stronger engines must be necessary for exhausting the gases than for pushing the cold air, and apparently forgets that even if the volume of the gases escaping at 400° is greater than of the ordinary feed air, a pound of air is but a pound, and the extra power required of the engine is only the trifle due to the greater size of fan required for the volume, but the actual work due to the gases will be the same. I look, however, to small fans in the future even for exhausting, driven by high-speed motors.

I need perhaps hardly point out the glaring inconsistency be-

tween the law laid down by Mr. Howden on page 39, as follows: "It is evident, therefore, that this system of the suction-draught cannot, even under the very best conditions in which it could be placed on board ship, at a high rate of combustion, approach the system of the writer in efficiency or economy," and the paragraph on page 42, relating to the American Line steamship "Berlin," in which the "Ellis & Eaves" combination suction-draught is now being tried against the previous Howden arrangement. The paragraph in question reads as follows:

"The boilers are now fitted with 'Serve' tubes, which of themselves should give an increased steam supply of 10 per cent from the same quantity of fuel formerly consumed. The air-heating surface in horizontal tubes will probably be also in this case about six times greater than the air-heating tubes were with the writer's system. There should be therefore considerably better results in this steamer with all these additional improvements and expenditures, even though the efficiency of the system should actually be considerably less than in the one removed."

The different portions of the last sentence will require some reconciling. Meanwhile I will only say that the "Berlin" is with the same boilers showing considerably greater horse-power with her main engines, and yet some economy; so that Mr. Howden's momentary prophetic mood on page 42 is realized in preference to the earlier "law of nature."

Mr. Howden assumes that in this system of "suction" draught a large volume of cold air must pass into the furnace when the door is opened. The "Berlin" and the two new steamers "Kensington" and "Southwark," now being finished for the American Line, are fitted by them with dampers which close and open automatically, as the fire-door is opened or shut; but it is noteworthy that the first boilers on this system at the Atlas Works, Sheffield, have now worked for nearly two years without using dampers (except when cleaning the grates), without leaky tube-ends resulting, although burning continually from 35 to 60 lbs. per square foot of full-size grate, as no other existing Scotch marine type boilers have done. Owing to the low temperature of the gases when entering the fans, these also have stood the work satisfactorily. We shall see what we shall see.

Mr. Howden.—Mr. Chairman: Several questions have been asked and a number of statements made in the discussion of my paper which I will endeavor to notice and reply to as well as I can.

In the first place, Mr. Kafer, in his remarks, inquired whether it was better to utilize the heat of the waste gases in heating the

air of combustion or in heating the feed-water, and also if I had made any experiments to determine absolutely which is preferable. These points I have already dealt with in previous papers on the subject.* It has also been tested practically to the fullest possible extent by the late Mr. E. Kemp of Glasgow, who has been referred to by Mr. Dickie as an old friend. Mr. Kemp, in the endeavor to utilize the heat of the waste gases from marine boilers by heating the feed-water, went to enormous expense in making the feed-heaters so large that their tube-surface was several times greater than the total heating-surface of the boilers to which they were attached, and the feed-water from the time of entering the feed-heater took some hours to pass through it before reaching the boilers. There were two steamers so fitted by Mr. Kemp. In the first the fire gases circulated around the tubes, the feed-water being inside; and in the second the feed-water was outside the tubes (which in both cases were horizontal), and the fire gases passed through the tubes. In both cases the water passed through four sections of the feed-heater, in which, with its great heat-absorbing surface and the long period the comparatively small quantity of feed-water remained in contact with the fire gases, the greatest possible utilization of the waste heat should have been effected.

In the first steamer fitted with these immense feed-heaters, the corrosion of the tubes was so rapid and extensive that a large number required to be replaced every voyage, and in a short time the apparatus had to be removed. In the second steamer the corrosion was not nearly so rapid, and the number of tubes requiring to be replaced was consequently not so great nor so frequent as in the first steamer, but the expense of this system was so great that I do not think it is being continued.†

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* *Vide* Trans. Inst. Naval Archts., 1886, vol. 27, pp. 191–194; Trans. Inst. Engineers and Shipbuilders in Scotland, 1888–9, vol. 32, pp. 212–214.

† Since making the above remarks at the Congress I have had an opportunity of ascertaining more fully the after-history of the steamers fitted by Mr. Kemp and of re-reading Mr Kemp's paper on the subject in the Trans. Inst Engineers and Shipbuilders in Scotland for 1888–9, pp 206–212. The first steamer fitted was the "Bléville," in which the feed-heater worked only about six months, when it was removed, and shortly thereafter the boilers were replaced by others. The temperature of the feed-water entering the feed-heater was 130° and leaving it 280°, when the temperature of the fire gases leaving the main boilers was 750° and leaving the feed-heater 350°. The second steamer fitted was the "Caloric," owned by Mr Kemp himself, the surface area of the tubes in the feed-heater of which was 2 173 times that of the total heating-surface of the boiler, and the calculated time taken by the feed-water to pass through the feed-heater was 2 hours 26 minutes. The tubes in the

The expense of construction of this feed-heating apparatus also is so great, and the space occupied by it in the ship so extensive, that, supposing it was otherwise as good as heating the air of combustion, steamship owners could not afford to use it. The utilization of the waste heat of the fire gases by the air of combustion as used in my forced-draught system is found, however, to be greatly more effective. The heat is there extracted in the shortest possible period of time. Air has had the reputation of being a very bad conductor of heat compared with water, but I know of no conductor of heat so good as air used in the manner in which it passes through my air-heaters, where it is broken up and thoroughly mixed by impinging on the heated tube-surfaces. I have not the figures beside me, but I have shown in some of my writings the incredibly short space of time in which air absorbs heat when used in a certain way, and also how vastly superior it is to water as a heat-absorbent when so used.*

The advantage, therefore, of heating the air of combustion instead of the feed-water is so enormously great, that no one after studying the question put by Mr. Kafer, and finding how much easier and much less expensive it is to extract the heat of the waste gases by means of air, as in my system, would ever attempt to utilize it by feed-heating. There are also the other advantages accruing from the heating of the air of combustion. It is not merely the greater amount of heat taken up by the air from the waste fire gases: there is also the beneficial effect of this heated air when it reaches the furnace. It is generally supposed that the advantage is merely the value of the number of units of heat taken from the waste gases that should be credited, but, as I point out in my paper, there are many other concurrent advantages arising from

feed-heater of this steamer, as I mentioned, did not corrode nearly so quickly as those in the feed-heater of the "Bléville," though they also eventually gave way. Fourteen tubes had given way by the end of the voyage before Mr. Kemp's paper was prepared. I have now learned that the maintenance of the feed-heater in the "Caloric" eventually became so troublesome and expensive that it was removed, and this steamer is also now being fitted with new boilers.

* *Vide* Trans. Inst. Engineers and Shipbuilders in Scotland, vol. 32, pp. 212, 213, where it is shown in the discussion of Mr. Kemp's paper that in $\frac{1}{5}$ of a second 11.4 times more units of heat were absorbed by the air from a given surface area in one of my air-heaters than was absorbed by the feed-water from an equal surface of Mr. Kemp's feed-heater in the "Caloric" in 9.125 minutes—that is, the much greater heat-absorption by the air was effected in $\frac{1}{2737.5}$ part of the time taken by the feed-water to absorb the smaller quantity of heat.

the increased heat of the air of combustion. In the first place, the average temperature of the furnace is raised by an amount equal to the number of degrees the air of combustion is increased by the heat of the waste gases. This higher temperature of furnace again renders the heating-surface of the boiler more effective. We all know that the rapidity with which heat passes from one body to another depends on the difference of their temperatures, so that the higher the temperature of the furnace the greater will be the difference between the temperature of the water in the boiler and the temperature of the furnace, and so much more quickly will the heat pass through the plating. By this means a square foot of heating-surface will be more effective in the furnace with the high temperature than it is when the temperature is lower.

There is also this other advantage in heating the air of combustion: it produces a condition of the furnace more favorable for economical and rapid combustion by more quickly gasifying the solid carbon of the fuel, and thereby reducing the weight of air required for its combustion. The oxygen in the air of combustion enters into combination with the carbon of the fuel in the gaseous state, and the more quickly the carbon is gasified the more easily and readily does the oxygen combine with it, and less surplus air is thereby required in the furnace for the combustion of a given weight of fuel. This more favorable condition of the furnace, arising from the utilization of the waste heat by the air of combustion and from using less air for a given weight of fuel, produces still further advantages by the reduced quantity of gases passing more slowly through the tubes and giving up more heat to the water.

I have given some figures in my paper to show the effect of this feature in reducing the velocities of the gases through the tubes. This is a point affecting the economy of steam-boilers to which I have never yet seen any reference in any book or paper on the economies of combustion. It appears to have been hitherto quite overlooked, but it is a very important point in economical combustion and efficiency of the heating-surface of a boiler. Heating the air of combustion, as in my system of forced draught, produces, therefore, very different results from those obtained by pushing an indiscriminate quantity of cold air through a furnace at a rapid velocity. This brings me to another point: Mr. Kafer seems to have an idea that with cold air you can have a higher rate of combustion than with hot air, and says that I have economy more in view with my system than maximum power. I entirely disagree with Mr. Kafer in these ideas. What I aim at is a high evapora-

tion from a given quantity of fuel in a given time; and both a higher rate of combustion in a given boiler and a higher economy can be attained with hot air than with cold. You can effect a high rate of combustion with cold air, but the higher the combustion the higher is the temperature of the gases going up the chimney; for in forcing the larger quantity of gases at a greater velocity through the boiler a less proportion of their heat can get into the boiler. It is true that in a locomotive there is a very high combustion obtained with cold air, but there is also a very high heat in the firebox, which makes the conditions of combustion in the locomotive very favorable; but at the same time a very large quantity of air passes through the locomotive boiler under a difference of pressure of perhaps seven or eight inches of water between the bottom of the furnace and the chimney. The important economic factor in the locomotive boiler in conjunction with the high furnace temperatures is the large number of small, long tubes, which divide the heat into small streams and cause it to be more rapidly taken up in passing through them.

The high air-pressure necessary for this treatment cannot be got on board ship without great expense, the exhaust-steam not being there available as in the locomotive for the purpose of creating draught.

Mr. Kafer has referred to the extension of the air-reservoir into the stoke-hold as an objection to my system; but, as Mr. Dickie has pointed out in his remarks, this is of small consequence, as the air-reservoir extends very little beyond the usual projection of the furnace-doors, while you can get much nearer to the boiler front with my system than to the front of a boiler not so encased or worked with natural draught. You can stand quite close to the fire-door with my system, as no radiation passes from the furnaces to the stoke-hold. Another point is the preference given by Mr. Kafer to ash-pit draught over the closed fire-room draught; but, as I point out in my paper, that depends on the manner in which the ash-pit draught is applied. One must discriminate between the kinds of ash-pit draught. As mentioned in my paper, the first to try, so far as I can ascertain, ash-pit, suction, and closed fire-room draughts by means of air supplied by a fan, was Mr. Edwin A. Stevens. It is only very lately that I came upon the facts in relation to those early investigations and operations in forced draught, but they leave no doubt whatever on my mind that to the late Mr. Edwin A. Stevens belongs the honor of being the originator of these three different systems in steamships; and I have peculiar pleasure indeed in finding that he is represented here to-day so ably

by his son, Col. E. A. Stevens, who has materially contributed to the success of this Congress by the effective manner in which he has taken part in the discussions of various papers.

What I meant to speak of in regard to the manner of working with a closed ash-pit was, that the troubles which Mr. Stevens found in working that system led him to try the other modes, and that these troubles, as I have stated, were exactly those I found in the trials with a closed ash-pit, made by me in 1862, with the boiler roughly illustrated in my paper. You require therefore to discriminate in regard to the manner of working closed ash-pits. A closed ash-pit is a part of my system, but there is much more than this feature in it; and until I added the air-reservoir and double doors to balance the air-pressures above and below the fires, and the regulating-valves to admit proportioned quantities above and below as required, I was unable to work furnaces either economically or efficiently with cold air, and not at all with hot air. Now, I have not yet found that any one in any country ever used a balanced air-pressure over the fire-doors, or used valves for admitting the air, cold or hot, above and below the fires in conjunction with a closed ash-pit, before the date of my patent. I have made extensive inquiries on this matter during the last ten years in my own country, in Germany, France, and in the United States, and I have not found one who had seen a single case before the introduction of my system. This system alone brings the admission of air into a furnace in an accurate, effective, and controllable form.

The quantity of air admitted can be proportioned to the amount of fuel required to be used, and also to the quality of the fuel used. If it is a bituminous fuel, more air is wanted above than with non-bituminous. This operation is regulated with ease, and all other operations of the furnace likewise. Now this cannot be done by simply blowing air into a closed ash-pit. It has often been tried, but it has always been given up. I do not know exactly how Mr. Kafer admits the air into the furnaces, but, where it differs from the original plan of Mr. Edwin A. Stevens, I fancy Mr. Kafer has had considerable help from the study of my system in regard to this air admission to the furnaces.

Regarding the steamer referred to by Col. E. A. Stevens, the name of which he thinks was the "Golden City," as having been running to South America some time between 1860 and 1870 with closed stoke-hold forced draught, I would like very much to have further information. I have not yet been able to get information of any steamer whatever running continuously at sea at a power that could be termed forced draught before I began my system,

though there may have been trials in harbor. Col. Stevens mentions that he believes the application was not entirely successful in the steamer referred to. What I have claimed at every meeting during the last eight or nine years where such matters have been discussed is, that the "New York City," which I fitted in 1884, and which has continued running to this day, was the first vessel that ever used forced draught successfully as a normal condition of working in a sea-going steamer. This claim has never yet been seriously called in question.

Col. Stevens asked a question regarding the control of the combustion in my system by stopping it entirely when wanted, which I have pleasure in answering. This feature of controlling the combustion by complete stoppage I consider a very important part of my system, and especially for war ships. For steamships working steadily at sea for weeks together, it does not require to come into operation so much; but for coasting vessels, and especially for war ships, which may have to stop suddenly with full steam on and start again at full speed after stopping for a considerable time it is of great service. In case of sudden stoppage with the steam only slightly under the loaded pressure no steam need blow off at the safety-valves, as the shutting of the air-inlet valves to the furnaces immediately suspends the combustion, and consequent evaporation, and prevents blowing off. The fires may be kept in this quiescent state for a considerable period without loss of steam-pressure, and in a few seconds after the air is readmitted the furnaces are again bright with flame and the boiler in full evaporation. With a closed stoke-hold draught it is quite different. If the engines are suddenly stopped, the steam, under similar conditions, must blow off rapidly, and many difficulties ensue, as the fans must continue to run to give air to the stokers and sustain at least an atmospheric pressure in the stoke-hold. The evaporation, therefore, must go on, and steam must blow off in boilers fitted with closed stoke-holds when the engines are stopped. With my plan, the shutting off the air from the furnaces by the valves, which can be done in one or two seconds, prevents combustion and evaporation, so that if the steam-pressure is only a pound or two below the safety-valve load there will be no blowing off of steam, for in a very short period the tops of the fires become black and coke up, and the combustion practically stops. For coasting steamers which want to lie under steam for five or six hours, or more or less, this mode of working is very serviceable, or for steamers plying as ferry-boats, as mentioned by Col. Stevens. Of course when it is known that the steamer is to be stopped for a period, but is wanted

large diameter, if such could be admitted on board ship, the proportion of fan-power to evaporative power could, however, be considerably reduced, but, under the most favorable circumstances conceivable, the fan-power required for equal evaporative power of boilers would be on this system at least four times that required for the system of the writer. With a belt-driven fan the writer has obtained fully 2000 I.H.P. at a high rate of combustion from boilers on board ship with 8 to 10 I.H.P. expended by fan-engine. It is evident, therefore, that this system of the suction draught cannot, even under the very best conditions in which it could be placed on board ship, at a high rate of combustion, approach the system of the writer in efficiency or economy.

In working this system it is necessary that there should be one fan at least for each end of every boiler. When there are several furnaces in each boiler-end, if the fire-door is opened the fan of the power required for the number of furnaces will necessarily pull from the point of least resistance, which is the open furnace-door. This will cause a very strong draught of air through the open furnace, and for the time that the door is open the draught through the other furnaces will be reduced, while the combustion-chamber and tubes of furnace having its door opened will be rapidly cooled, and will, in due time, injure the tube-ends if some means of shutting off the furnace being operated on is not adopted. It is true that the heated air will to some extent be drawn in at the same time from the side valves. This may, however, be insufficient to save the tube ends, if the shutting off of the furnace, which is a troublesome operation, is not adopted.

A very singular advantage has been claimed by its promoters for this system, which they term *induced* draught, distinguishing it from what they term *forced* draught. The term "induced" draught, the writer considers, can only properly be applied to a draught carried, or led in, by the agency of a current or force moving in the same direction, as in a Gifford injector.

The popular term "suction" appears to the writer to be the proper distinguishing name for the system of draught adopted by Messrs. John Brown & Co. What they claim is that "with *forced* draught the flame and hot gases are forced under pressure upon the tube-plates and tube-ends, and must

1400 I.H.P., though their air-heating arrangement is not so high or so efficient as the style I am now using; but notwithstanding these deficiencies these boilers have given at sea with their ordinary firemen 24.7 I.H.P. per square foot of fire-grate—an efficiency or a rate of power per square foot of grate which has never been approached in any Admiralty four hours' trial with selected firemen and hand-picked coal.

I am now engaged upon three steamers for a foreign government in which each furnace, 3′ 6″ diameter, with fire-grate 5′ 6″ in length, is to give 500 I.H.P.; that is, 6000 I.H.P. from 12 furnaces. You must grant that this is an unusual power to take out of four single-ended boilers 13′ 6″ in diameter, being 26 I.H.P. per square foot of grate. There is, however, no difficulty in obtaining this, as has been already proved. It simply means a little higher air-pressure and a little higher air-heating than is now used in the American Line cargo-steamers, and that is simply arranged. Owing to the high economy of the system, it means only a rate of combustion under 40 lbs. per square foot of grate. I am aware that economy is looked upon in naval circles as a matter of small moment, the idea being that it is only for a short time a high power is required to be used; and they say, Let us drive in the coal: it matters not, if we get the power. This idea is, however, altogether wrong, for the more coal you put into the furnace with these cold-air systems the less power you get out of it, that is, the less power per pound of coal used. This is a very bad and unscientific mode of getting a high power. What is wanted is to get the greatest possible power with the least possible coal. My system affords the means of doing so with almost an equal economy at all rates of combustion. Now, in adopting a mode of obtaining a high power irrespective of economy, which I believe you do here as much as in England, you are defeating the very object you desire to attain, for the more you economize, the greater the power you can attain on the grounds I have stated in my paper. The course I am now following, of increasing the economy, at the same time serves the purpose of increasing the power, so that this 500 I.H.P. per 3′ 6″ furnace with a 5′6″ grate can be all the more easily obtained, because of the high economy in fuel.

In the written remarks of Mr. Ellis of Sheffield on my paper, forwarded after the conclusion of the Congress, which I have since had the opportunity of perusing, I find Mr. Ellis appears to hold the view that my system of forced draught, while very good for moderate rates of combustion, is not so well adapted as the suction draught which he advocates for high rates of combustion. This view of Mr. Ellis, for the reasons I have set forth in my paper, I

must hold to be entirely wrong, and that the opposite view is correct as regards the rate of combustion.

While it is quite true that with a very high power exerted by exhausting fans a high rate of combustion can be obtained by suction draught, it is also true that in the same boiler with my system, suitably arranged in the air admission and outlet details, an equal rate of combustion can be obtained with at least one fourth of the fan-power. There would be these further advantages with my system: (*a*) a greater saving of the waste heat of the fire gases with one fourth of the air-heating tube-surface; (*b*) a greater economy of fuel, arising from the superior utilization of the waste heat and the reduced proportional quantity of air admitted to the furnaces per unit of coal consumed; also, the absence of the cold-air admission necessary in Mr. Ellis's system; (*c*) saving of the largely increased space in the vessel required for the large fans placed over the boilers, as in Mr. Ellis's system; (*d*) saving the wear and tear of fan and fan engines inherent in Mr. Ellis's system from their working in highly heated gases, which must inevitably make these machines short-lived; (*e*) the greater comfort to the men employed in attending to the fan-power, saving them from the unavoidable heat always existing in a steamship over the boilers.

I am likewise compelled to dissent from Mr. Ellis's conclusion that "the more you push or force the air and gases through the boiler the more you increase your difficulties and troubles, whilst you have a clear course if you exhaust the gases by suction." Mr. Ellis in making this assertion gives no reasons whatever in support of it. As I have given, I believe, sufficient reasons in my paper in direct opposition to this view, I refer readers to what I have already written on this part of the subject. Mr. Ellis, in putting forward these ideas, appears to lose sight of the fact that the rapidity of the supply of air to the furnaces, on which the rate of combustion must depend, is due to the greater or less difference of pressure between the outlet or chimney end, and that at the ash-pits and furnace end, whatever mode is used; the area and passages between these two ends, also temperatures, being alike. Under equality in these two latter conditions the difference in pressures between the combustion-chambers and the smoke-boxes, whether suction-draught or pressure-draught is used, must be exactly alike to pass the gases from an equal quantity of fuel consumed, or, to state it still more correctly, to pass equal weights and temperatures of gases through in equal times.

In stating the case in this form for simplicity's sake, I am stating it more favorably for the suction-draught than it actually

should be, for, when the difference in pressures is equal in both cases the gases in the case of the suction-draught are under less pressure than that of the atmosphere, while with the pressure-draught the gases are under somewhat greater pressure than that of the atmosphere when working at a high rate of combustion. The higher the rate of combustion the greater becomes this difference in the pressures of the gases, descending further below the atmosphere with the suction-draught, and ascending further above with the pressure-draught.

The practical effect of this difference in actual internal pressure is, that the same weight or quantity of gases is in smaller volume in the pressure-draught boiler than in the other. This condition, as I have shown in my paper, makes the heating-surface more effective, as an equal amount of heat in the fire gases, from the same weight of coal consumed, is in smaller volume with the pressure-draught, and consequently passes more slowly and more easily through the furnaces, combustion-chambers, and tubes, and therefore gives up more heat per unit of coal consumed than is done with the larger volume and more rapid passage of the gases with the suction-draught.

Mr. Ellis still endeavors to show that, in similar boilers, an equal quantity and temperature of fire gases may exist in the combustion-chambers, or pass through the tubes; but that this quantity and temperature in the boiler using suction-draught will not impart nearly so much heat to the plating forming the combustion-chambers and tubes, as they will in the boiler using pressure-draught. If this idea of Mr. Ellis was correct, no stronger argument against the use of suction-draught could be found. Mr. Ellis fails to see that if the suction-draught prevents the heat to a large extent from being taken up by the heating-surface of the boiler, it must pass into the fan and be thrown by it into the chimney. The only other alternative on Mr. Ellis's view is, that with the suction-draught the combustion of the same quantity of fuel in a furnace gives off much less heat than when pressure-draught is used, and the combustion-chambers and tube-ends are thus saved by the suction-draught from injury.

This alternative, however, is equally bad for the reputation of the suction-draught. Mr. Ellis, therefore, in endeavoring to overturn my argument lands himself in a dilemma, with the usual uncomfortable consequence.

I must likewise take exception to Mr. Ellis's ideas regarding the necessary power required from the fans in handling the same weight of air and fire gases by the two systems. Mr. Ellis says I

after a few hours' trial. These leakages are generally so bad that the boiler is rendered useless, fires have to be drawn, and the tubes made tight before the boiler is again workable. These leakages also occur with this system in war-ship boilers even at low rates of combustion, and much has been said and written in trying to account for this serious defect of the system.

In his papers of 1884 and 1886 read at the Institution of Naval Architects the writer gave his explanation of the cause and predicted the serious consequences which would occur in navy boilers if the system was continued, before one hundredth part of the damages which have since occurred had taken place.

The writer will explain in detail how the injury to the tubes and tube-plates occurs, with the conditions and sequence of effects, in order that the matter may be more fully understood.

In a boiler worked on this system at a given evaporative power the temperature in the interior will at periods be higher than in a similar boiler with equal evaporation not worked on this system, because at the periods of firing and cleaning fires the temperature is much lower than in the other boiler.

When a rapid combustion takes place in boilers with "closed stoke-hold" forced draught, especially in navy boilers, which have more contracted spaces than are usual in mercantile steamers, there is necessarily a high temperature in the furnaces and combustion-chambers. The tube-ends for the following reasons must be higher in temperature than any other part of the combustion-chamber: Not being homogeneous with the tube-plate, the tube-ends in contact with them cannot transmit the common heat of the chamber so rapidly to the water as they would do if in molecular union with the tube-plates. The heat of any part of the metallic surface communicating the heat of the fire-gases to the water depends more on the rapidity with which the heat passes to the water, than on the temperature of the fire-gases themselves, as in the hottest part of the furnace the plates overhead are comparatively cool so long as the evaporation is unimpeded. The heat taken up by the tube-ends in contact with the tube-plate, the writer believes, reaches the water only to a small extent through the tube-plate, but chiefly by lateral conduction to

and through the part of the tube in contact with the water. As the surface of each tube inside the tube-plate has to transmit the heat it receives from the hot gases in contact with its own area, and also the greater part of the heat taken up by the area of the tube embraced by the tube-plate, it is evident that this can only be accomplished by the end of the tube being considerably hotter than the part inside clear of the tube-plate. The very hottest part of the tube must certainly be the extreme end inside the combustion-chamber. Doubtless all overlapping plates and rivets, for the same reasons, attain a higher temperature than the single plating, and consequently they are also sometimes damaged by the inrush of cold air, but owing to their thickness they are much less sensitive under a rapid change of temperature, as they cannot be cooled suddenly.

Though the combustion-chamber and tube-ends of a boiler worked with a closed stoke-hold attain a high temperature with a rapid combustion, no damage would arise from that temperature if maintained uniformly or without great variations.

In locomotive boilers it is found that the tube-plates and tube-ends are not damaged with much higher temperatures than can be found in any combustion-chamber of a marine boiler under the very highest forced draught. Fortunately there is no sudden change in the locomotive boiler by impact of cold air on the tube-plate either in running or standing. When steam is shut off the action of the blast-pipe is suspended, so that when the engine is stopped there is no inward draught, though the fire-door is open, and the fire-box continues subject to the glow of the incandescent fuel.

These saving conditions are absent in the closed stoke-hold system of working. When the combustion-chamber and tube-ends have been highly heated by the rapid burning of a heavy charge of fuel, though no harm is done so long as the furnace-door is shut, as soon as it is opened the conditions immediately change. If the fire is not well burned down and is very hot, the first rush of air is rendered comparatively innocuous by being rapidly expanded and reduced in velocity by the great heat of the furnace.

This conservative action of the hot furnace is, however, rapidly overcome by the continuous rush of cold air accu-

mulating in density and velocity as the furnace cools down, and eventually reaches the tubes and tube-plate before they have had time to cool down, at a temperature it may be 800° or 1000° less than that of the hot gases, which not many seconds before had been in contact with them.

The iron or steel tubes and tube-plates, it must be noticed, do not cool very rapidly after being highly heated, more especially when surrounded by a temperature considerably higher than themselves. When the cold current reaches the tube-plates the thin tubes with their hot ends being much more quickly affected by the change of temperature than the thick tube-plates, shrink suddenly and cause the inevitable leakage which has proved so disastrous in the boilers of war ships worked by this system.

It is not likely every time that a furnace-door is opened for stoking that the cold air reaches the tube-plate with the effect of causing the tubes to shrink suddenly, as, it may be, the cooling down is often sufficiently gradual, owing to the conditions of the furnace and the short period the door is opened. It is also very probable that the tubes are loosened, not by one or two shrinkages, but by a succession of shrinkages, like jars caused by the blows of a hammer. The leakage is, however, inevitable after a certain short period of working, and the writer is not aware that any war ship has ever been worked continuously for even a few days at a power equal to that of a good natural draught without being more or less injured. This injury also not unfrequently occurs with this system, even when working at a low power in some boilers. This apparent anomaly appears to the writer to be explained in this way: The occurrence generally takes place after the boilers have been under steam for some days. During the period of working the water in the boilers loses its original purity, and gets a trifle salt and a little greasy. This condition raises the temperature more or less of all the parts in contact with the fire-gases. The combustion, though not so rapid, yet raises the temperature of the plating considerably, and if a fire be burned low under these circumstances, the cold air, still under considerable pressure, will much more quickly find its way to the tube-plates at the difference in temperature sufficient to cause shrinkage of the tube-ends.

It should also be noted that with a closed stoke-hold there

must always be an air-pressure above the atmosphere; and though the admission to the furnaces may be restricted, the velocity with which the cold air rushes into the furnace when a furnace door is opened is not that due to the positive pressure cnly, but to that of the positive pressure of the stoke-hold combined with the minus pressure of the furnace due to the chimney, which, with only one eighth of an inch positive pressure, may create a velocity of current in some boilers of 30 to 40 feet per second.

The phenomena thus described, the writer believes, more or less correctly explain what actually takes place in producing leaky tubes in boilers worked with closed stoke-holds.

It should be mentioned that a protection for the tube-ends has lately been introduced in the British Navy. This is a long thin iron ferrule inserted into the tubes in the combustion-chamber, having a capped flange which covers the ends of the tubes. This ferrule will no doubt protect the tube-ends from the effect of the cold air while it lasts, but its lifetime can only be one or two days under full power, and probably ten or twelve days under reduced power. It will often prove a treacherous friend by giving out the moment when its services are most wanted. It is clear that such a protection can never insure safety in circumstances requiring the vessels to remain under steam for many days, or for working at a high power for any lengthened period of hours.

The other chief defect of this system is that of its wastefulness of fuel when worked at a high rate of combustion. This wastefulness is most noticeable in boilers of war ships, where the reduced dimensions and heating surface per I.H.P. bring the wasteful conditions more quickly into play. The greater the rate of combustion, as has been explained, the greater is the percentage of air required per unit of fuel. The velocity of the fire-gases through the furnaces, combustion-chambers, and tubes is correspondingly increased, making the heating surface less effective. There is consequently a great increase in the temperature and volume of the waste gases leaving the boiler, and the actual proportion of the total heat of combustion utilized for evaporation may thus be less than one half, as has been already illustrated.

It will show how much the quantity of air required for combustion per unit of fuel and the high temperature of the

to the probable use of small fans running at a high speed, but such fans would not make the relative proportions of power required by the two systems more favorable for the exhausting-fan; it would very probably be less favorable.

Mr. Ellis finds some inconsistency in the paragraphs which he quotes from my paper in reference to the case of the "Berlin." In these quotations I refer to the fact that the boilers of the "Berlin" had, in conjunction with Mr. Ellis's arrangement, been fitted with "Serve" tubes and with an air-heating arrangement having, probably, six times more tube-surface than was used in my air-heater, and therefore said that with these additions better results should be obtained even though the efficiency of Mr. Ellis's system in itself was actually considerably less than the one removed. This remark appears to be quite consistent, and does not require further explanation.

I believe I am quite warranted by facts in concluding that had but a small part of the great expenditure involved in refitting the "Berlin" with Mr. Ellis's plan been employed in improving my system in that steamer according to present experience and especially the experience obtained of the actual needs of the boilers of the "Berlin" herself, an improvement would have been obtained of much more decided value than the doubtful results realized from the use of Mr. Ellis's system, combined as it is with the other effective additions of "Serve" tubes, etc.

That something like this is the opinion of the Company themselves after their experience of the actual working of Mr. Ellis's plan over a considerable period may safely be inferred from their having subsequently adopted my system for their new large passenger steamers now being built at Philadelphia.

XLIII.

THE APPLICATION OF FORCED DRAUGHT TO THE FURNACES OF MARINE BOILERS, AND THE DEFECT OF LEAKY TUBES RESULTING THEREFROM.

By HENRY BENBOW, D.S.O.,

Chief Inspector of Machinery, Royal Navy.

In submitting for your consideration this paper on the application of forced draught to the furnaces of marine boilers, and the defect of leaky tubes resulting therefrom, I fully realize the responsibility I have incurred by undertaking to write upon so difficult and important a subject, as to which there exists such a diversity of opinion amongst the members of the engineering profession; and although the views herein expressed may not coincide with those held by many here present, I trust the points to which I am about to call attention may be considered of sufficient interest to warrant a fair discussion on your part.

Whether the arguments advanced are in favor of or against the views I have expressed, I feel certain some valuable opinions will be given and important information gained therefrom, tending to advance this difficult problem a step farther towards its final solution; and if such a result is obtained, I shall consider that my effort to this end has not been thrown away.

I propose, with your kind permission, to avoid all theoretical arguments,—as theory often sounds well, but fails when put in practice,—and will therefore confine myself entirely to the practical side of the question, pointing out some of the

the writer's system than with the closed stoke-hold or in any system with cold-air supply. The cause of this has already been explained when describing the effect of the supply of hot air for combustion.

The maximum temperatures of the other systems for equal evaporation are considerably higher to compensate for the much lower temperature to which the furnaces and interior parts of the boiler are brought by the scour of cold air to which they are subjected when the furnace-doors are open.

These endeavors to show by well-known principles and plain figures the causes which affect economy and wastefulness in boilers are well sustained by facts. It is within the experience of many, that with boilers on the closed stoke-hold system, worked at a rate of combustion as high as will produce a steam supply to triple-expansion engines of 20 I.H.P. per square foot of fire-grate of ordinary size, a consumption of 2.6 lbs. of fuel per I.H.P. per hour, and in some cases even more, is required.

It is also well known to many that with the writer's system 20 I.H.P. per square foot can be obtained on a fire-grate of ordinary size on very much less than 1.6 lbs. per I.H.P. per hour.

The expenditure of 1.6 lbs. has been assumed here to meet the case of the supposed more wasteful engines of war ships and cruisers when working at a power requiring as much as 20 I.H.P. per square foot of fire-grate of their boilers.

In bringing this paper to a conclusion the writer has to plead in extenuation of its length and diffusiveness the fact that it has been written at odd hours, and at considerable intervals, as the exigencies of his business permitted. He has endeavored to cover most, if not all, of the ground occupied by the different modes in which forced draught has been attempted, and to point out in the plainest manner and with the simplest possible calculations the principles and natural laws which govern and determine the effects of the use of air-pressure in combustion of fuel in furnaces. The writer trusts that his unelaborated attempts to show these principles will make this important subject better understood, and that his contribution to this great historical congress may not be altogether valueless.

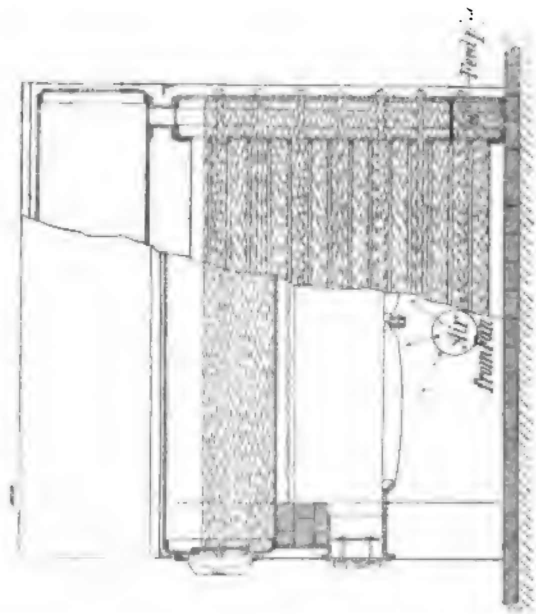


Fig. 2

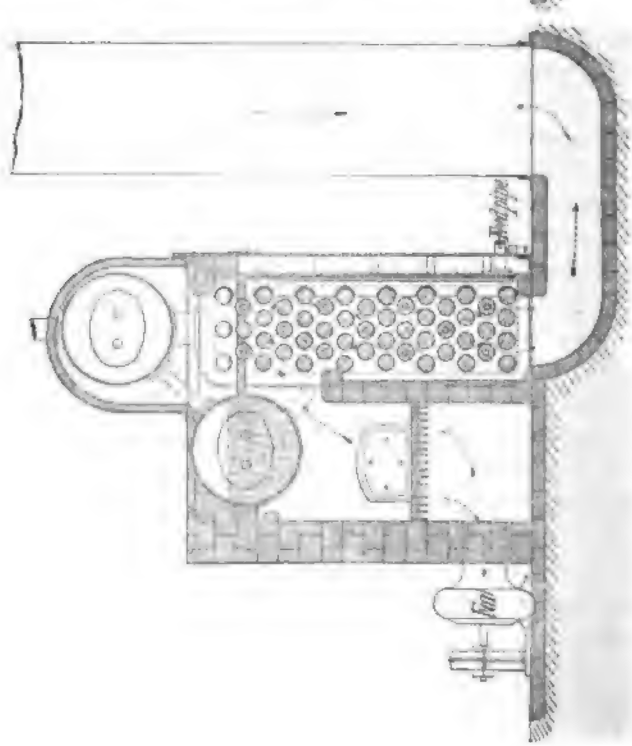


Fig. 1

obtained with fewer boilers worked under forced draught; and, although much difficulty has hitherto been experienced, and some few accidents have occurred from leaky tubes, I feel certain that there is not an engineer or a stoker in the British Navy who would advocate its discontinuance.

In our naval service, air is supplied to the furnaces under pressure by fans worked with separate engines in a closed stokehold, by which means the amount of air-pressure required is easily regulated. This system works very satisfactorily, and the constant current of fresh air passing through the stokehold keeps the temperature comparatively low, and comfortable for the men attending to the fires. The principal drawback to this arrangement is, that the wind from the fans raises a continuous cloud of coal-dust, which finds its way into the bearings and other working parts of the fan and feed-engines, causing abnormal wear of all the exposed working parts—so much so, that I have known the bearings of these engines to be completely worn out after a few days' steaming. In the latest designs the engines for driving the fans are placed outside the stokehold bulkhead, or are enclosed in a protective iron casing; and I consider it equally desirable that the boiler feed-engines should also be removed from the stokeholds, or at any rate closed in, to protect them from the coal-dust.

When this system of supplying air to furnaces under pressure was first adopted in our Navy, the maximum indicated horse-power to be developed in each ship was calculated on the assumption that the boilers could be worked with an air-pressure in the stokehold equal to a column of 2 in. of water, but only in one or two instances have they been able to stand this amount of pressure without the tubes leaking badly.

The greatest trouble from this defect has been experienced in the double-ended boiler with return-tubes and common combustion-chamber, similar to those on board our first-class cruisers "Blake" and "Blenheim;" and also in the locomotive type, as fitted to the torpedo-catcher "Sharpshooter" and her class. In this latter type the difficulty is increased by the tubes having been placed in rows diagonally; so that, although the tubes are $\frac{3}{4}$ in. apart, there is only a clear space of $\frac{1}{2}$ in. between the vertical rows for the steam to escape upwards; this must impede the circulation, by checking the flow

of water needed to replace that converted into steam close to the tube-plate. An arrangement for artificial circulation was fitted by the contractors of the machinery in H.M.S. "Sharpshooter," consisting of a screw-impeller working in a tube about 12 in. in diameter at the bottom of the boiler, and driven by a small engine placed in the stokehold to draw the water from the cooler end and deliver it through a diaphragm about 18 in. from the tube-plate. The principal objection to this contrivance was the presence of the diaphragm, as was demonstrated at the trial; for when the artificial circulation failed, owing to the apparatus breaking down, the diaphragm impeded natural circulation, the tube-plate shortly after became overheated, and the tubes leaked badly.

The next expedient tried was the fitting of porcelain ferrules in the ends of the tubes, and plastering the tube-plate with a fireproof cement composed of fire-clay, asbestos fibre, and a patent compound called *purimachos*. This met with partial success, so far as to prevent the tubes from leaking as long as the cement adhered to the plate and the ferrules remained clear; but the fine ashes driven forward by the forced draught adhered to the melting or softened porcelain ferrules, filling up the entrances to them more or less by bird's-nesting; the cement also became detached from the plate after steaming a short time.

Finally, a number of tubes were removed in vertical rows, to facilitate the circulation of the water, after which the trials, up to a limited indicated horse-power, were made successfully; but the boilers of this vessel, and of her sister ship, the "Spanker," have now been condemned as unsatisfactory, and it is proposed to use them for experimental purposes before replacing them by others.

With regard to the double-ended boiler having return-tubes and common combustion-chambers, several plans have been tried to prevent the tubes from leaking, such as rolling the tube ends with a special tube-expander that formed a ridge inside and outside the tube-plate, with a view to preventing end-motion of the tube; also the removal of two vertical rows of tubes over each furnace, and the fitting of Thom's patent circulators, neither of which has given satisfactory results.

The introduction of what is termed the "Admiralty ferrule"

has to some extent overcome the difficulty; unfortunately, these ferrules have a tendency to burn away, but they can easily be replaced.

It will be observed, by referring to the accompanying sketch, Fig. 1, that the end of this ferrule is mushroom-shaped, which protects the joint between the tube and tube-plate from the intensely heated gases, and leaves an air-space between it and the inner face of the tube for a distance of about 1½ in., so that the heat is conducted to the tube well beyond the inner surface of the tube-plate. It is found that if the end of the ferrule is turned, and fits closely in the tube, the conduction of heat from one to the other is improved, and the life of the ferrule thereby prolonged.

The material of which these ferrules are made is malleable cast-iron. Ordinary cast-iron has been tried, and also copper; the former was found to burn away very quickly, which was not the case with the latter, although the melting-point of copper is much below that of cast-iron. This is accounted for by the better conductivity of the copper; but the ferrules of this material would not remain tight in the tubes, and any moisture getting between would set up galvanic action; they are therefore considered unsuitable.

In the more recently constructed double-ended boilers the common combustion-chamber has been done away with, and each furnace is provided with a separate one; dampers are also fitted in the uptakes, to be kept closed while the furnace-door is open, in order to check the cold air passing through, for it was considered that the large quantity of cold air passing over the fires, when the furnaces were fired, caused the tubes to leak. This fitting did not overcome the difficulty; and, after close observation and a few experiments, the conclusion arrived at was that the oil used for internal lubrication of the machinery found its way into the boilers with the feed-water, and adhered to the inner surface of the tube-plate, retarding the conduction of heat to the water, and thereby causing the plate to become overheated and the tubes to leak.

To prevent this, grease filters or extractors have since been introduced for removing oil from the feed-water before it passes into the boiler; and H.M.S. "Phœbe" is fitted with these, but they failed to prevent the serious accident which

recently occurred on board that ship, when an engineer officer and two stokers were severely burnt, owing to the tubes in the two after boilers (while being worked with an air-pressure of ½ in.) suddenly giving out during an official trial. This caused a back-pressure in the combustion-chambers, which drove the flame back through the open furnace-doors. On examining the interior of the boilers afterwards, it was observed that the two after ones contained more greasy matter than the two forward ones; and, upon further investigation into the cause of this, it was discovered that the bulkhead forming the division between the oil compartment and the feed-tank, which supplied these two after boilers, had leaked, and that some of the oil had passed through, and, mixing with the feed-water, had been pumped into the boilers; it was to this that the accident was attributed.

Some experiments were recently carried out at Devonport Dockyard to ascertain, by means of fusible plugs, the temperature of the tube-plate close to the tubes, and to determine the limiting temperature to which the joint between the tube and tube-plate could be raised before leakage took place. The results showed the temperature near the tube at the centre of the thickness of the tube-plate to be 550° Fahr. when the boiler was generating steam at 150 lbs. (i.e., of temperature 366° Fahr.), the air being supplied to the furnaces at ½ in. pressure. It was also found that tubes leaked when the temperature of the plate near the joint rose to that of melting zinc, viz., about 750° Fahr.; which proves the necessity for avoiding all additional causes of overheating, and also for protecting the joints of the tubes with the plate (as is done by the Admiralty ferrule) in boilers where the tubes are simply secured in place by rolling, a method which is, in my opinion, quite inadequate, if the use of forced draught is to be continued with any degree of success.

Before the introduction of forced draught, little trouble was experienced from leaky tubes, although I have known instances when the tube-plate of a boiler has been coated with a salt deposit of ½ in. thick, which must have considerably checked the conduction of heat from the plate to the water. I served a commission in a ship fitted with trunk-engines, and, when steaming, the tallow used for lubricating the trunks

found its way into the boilers in large quantities with the feed-water, but without any bad effect on the tubes.

I have also frequently seen boilers blown out after steaming and run up with cold water almost immediately, and I resorted to a similar expedient for rapidly cooling a boiler when serving with the Nile Expedition for the relief of General Gordon in 1884–5. I was on board the S.S. "Safia" when a shot entered her boiler, and did not hesitate to pump out the hot water as soon as possible and replace it with cold, in order to expedite the necessary repairs, which did not cause a single tube to leak.

All the boilers I have seen thus treated, however, were of the old and obsolete type, worked at low pressures and fitted with brass tubes, which, being more ductile than the iron or steel ones now in use, were better able to accommodate themselves to any alteration of form that might take place in the tube-plate, either through expansion when steam was raised, or through contraction when the fires were drawn; and although by the introduction of steel tubes the galvanic action set up by the use of brass ones has been avoided, I feel certain that their adoption has added to the difficulties we have lately experienced from leaky tubes.

Such treatment as I have described would have a very different effect upon boilers of the present day, which require every possible care. Precautions are taken to insure their cooling down gradually after steaming, by allowing the fires to die out, and by excluding cold air from the furnaces and combustion-chambers for at least 24 hours afterwards; great care is also taken to prevent oil or grease from entering them with the feed-water, but none of the means hitherto adopted to effect this have been entirely successful.

It is now generally acknowledged that the prevalence of leaky tubes is in a great measure due to the high temperature of the tube-plate, consequent on the larger consumption of coal per square foot of grate surface when forced draught is used. It is therefore evident that if the conduction of heat from the tube-plate to the water is impeded by the presence of oil or by defective circulation, the probability of leaky tubes is increased. Such being the case, it will be well to consider the effect of this overheating upon the tube-plate.

It is well known that if a plate of metal be placed over a

fire or Bunsen burner, while the upper face is kept cool with water it will curve towards the fire to an extent proportionate to the difference of temperature between the two surfaces and the thickness of the plate; and, if stays were fitted at intervals, it would buckle between the stays. In my opinion, this is just what takes place in a tube-plate fitted with special stay-tubes—more particularly when it becomes overheated; therefore, to reduce to a minimum this tendency to buckle, the tube-plate should be as thin as practicable, and every tube of equal thickness—each forming a stay. Then, again, there is the lengthening of the tubes due to expansion to be considered and provided for, and also the expansion of the plates forming the sides of the combustion-chamber of the boiler.

We will take, for example, a double-ended return-tube boiler with common combustion-chamber. The chamber is rigidly secured—transversely by stays, and longitudinally by the tubes to the shell of the boiler. When steam is raised, the longitudinal expansion of the combustion-chamber and tubes must of necessity be greater than that of the boiler-shell, owing to their higher temperature, but for this no provision is made; consequently, either they must become distorted, or the ends of the tubes must be forced from their position in the tube-plate.

This might probably be prevented by the introduction of corrugations or an expansion-joint in the sides of the combustion-chamber, or by curving the sides so as to make the chamber less rigid; also the removable stays, that tie the lower end of the tube-plate and furnaces to the two ends of the boiler, should be given sufficient play to allow the tube-plate to accommodate itself to the longitudinal expansion of the tubes.

The method of securing the tubes in the tube-plate is, in my opinion, a most important consideration, especially if thinner tube-plates are to be adopted, which it is generally admitted would be an advantage. The present system of turning the ends of the tubes in a lathe, and simply rolling them in the holes of the tube-plate at the combustion-chamber end, should be discarded, and some better plan adopted; for it is very essential that the tubes should be rigidly secured at this end in order to exclude all scale, dirt, grease, or other

foreign matter from the joint. The contact between the tube and plate should be as perfect as possible, to provide for the free conduction of heat from one to the other; for if otherwise, the tubes, being thinner than the plate, and therefore more susceptible to variations of temperature, would, when cooling, contract quicker than the holes in the tube-plate, and consequently leak.

Some experienced engineers contend that the tube-plate, when heated, expands into the holes, thus tending to crush the tubes, and that certain experiments which have been made, support this theory. Whether such be the case or not, it certainly cannot account for tubes suddenly giving out during a steam trial, which has so often happened; indeed, this action should, for the time, tighten the tubes in place.

I have known instances of tube-ends having been found quite loose in the holes when the boilers have cooled down after steaming; but this might result from an imperfect metallic connection between the tubes and tube-plate, causing the tube-ends (by reason of the heated gases passing through them) to be raised—more especially when forced draught is used—to a higher temperature than the plate, and therefore by their own expansion to become crushed in the holes; when cold they would be of less than their original diameter, and necessarily loose in the plate.

The plan I would propose for securing the tubes is shown in the accompanying sketch, Fig. 2. When the holes in the tube-plate are bored, they should be faced on the inner side to form a narrow seating (about one-eighth inch wide), and a groove formed around the hole on the outer face of the plate. The tube-ends should be upset sufficiently to admit of a shoulder being turned upon them to bear against this seating, then lightly rolled in place, and the outer end beaded into the groove.

This would secure a perfect metallic joint, and the connecting surface between the tube and tube-plate would be more than doubled—which is an important consideration for the free conduction of heat from one to the other. The thin tube-plate would then be firmly held between the shoulders on the tubes and the beaded ends—no special stay-tubes being necessary, as each tube would form an efficient stay. The holes in the back tube-plate would require to be made

large enough for the shoulders on the tubes to pass through; the other ends of the tubes having been enlarged could be rolled in place in the ordinary manner, and, if necessary, beaded over.

To ascertain whether steel boiler-tubes would stand this treatment without splitting or being otherwise injured, a hole was bored in a piece of steel plate faced on one side, and a groove was turned around the hole on the other; the end of an ordinary steel tube was upset, and a shoulder turned upon it, and the tube-end fixed in the plate as described above without difficulty. The plate and tube-end were then cut longitudinally through the centre to show the connection between the two; but the contact was so perfect that the joint could not be traced. Beyond this the method proposed above for securing boiler-tubes in the tube-plate has not been tried.

The material best adapted for boiler-tubes is another important consideration. Passing over copper and brass as unsuitable on account of galvanic action, mild steel is undoubtedly the best, but it must be of suitable quality, very ductile, and with a tensile strength of about 23.5 tons per square inch. To show the advisability of this tensile strength not being greatly exceeded, I will quote an instance that came specially under my notice while holding the appointment of Chief Inspector of Machinery at Devonport.

The machinery and boilers for two gun-vessels were constructed at that yard, and when completed the steam trials were in every way satisfactory. In the following year two similar sets of machinery and boilers were constructed for two other vessels of the same class; but every attempt to get them through their steam trials failed, owing to the boiler-tubes on each occasion leaking badly. The failures were entirely due to the boiler-tubes fitted in these last two vessels not being sufficiently ductile, having a tensile strength of about 30 tons per square inch, whereas those fitted in the first two were of only about 25 tons per square inch. Eventually the defective tubes were replaced by others of less tensile strength and of a more ductile quality, after which not the slightest difficulty was experienced in these two ships from leaky tubes when the air was supplied to the furnaces at $\frac{1}{2}$ in. pressure.

Too much attention cannot be paid to the first fitting

of a tube in its place; for, if the joint between it and the tube-plate is not sufficiently tight—as is very often the case—to exclude the water under the first water test of 90 lbs. above the working pressure, it remains there when the boiler is emptied, and oxidation takes place, by which an inferior conductor is introduced into the joint—sowing the seed for future troubles. The boiler is again subjected to a second similar water test when placed on board a ship, and more water is forced into the already imperfect joints, increasing the evil; then, some time after, steam is raised for the trial of machinery, when the joints are more or less disturbed by the longitudinal expansion of the tubes, and by the buckling of the tube plate where stay-tubes are used. Then follows the forced-draught trial, by which the joints are subjected to a still heavier strain, on account of the higher temperature that forced draught entails. If the imperfectly fitted tubes remain tight until the termination of the trial, they are probably found leaking when the boiler has cooled down. They are then re-rolled, and considered efficient; but the imperfect metallic contact between the tube and plate still remains, to make itself more apparent on some future occasion.

From the foregoing remarks a general idea, I trust, may be gathered of my views on the subject of forced draught and the causes of leaky tubes; but before concluding this paper, I would like to call attention more particularly to the following points:

1. Adequate provision ought to be made for the longitudinal expansion of the tubes and combustion-chambers.

2. The combustion-chamber tube-plate should be as thin as practicable.

3. The tubes should be of a suitable ductile material: if of steel, with a tensile strength of about 23.5 tons per square inch; the ends rigidly secured to and in perfect metallic contact with the tube-plate. They should all be of equal thickness, each forming an efficient stay, and not less than 1 in. apart.

4. When raising steam, all fires ought to be lighted in the boiler at the same time, about 10 or 12 hours before steam is required, and allowed to burn up slowly. The practice of lighting the fire in the lower middle furnace some time in advance of the others, for the purpose of warming the boiler

gradually, is not advisable, as it causes unequal expansion of the tubes and tube-plate. The tubes directly over this furnace have been known in consequence to commence leaking, and to take up again soon after the other fires were lighted

5. Every care should be taken to exclude, if possible, oil or grease from the interior of the boiler.

6. After steaming, the fires should be allowed to die out, and the furnace and ashpit doors kept closed, if practicable, until the boiler has cooled down.

DISCUSSION ON EFFECT OF FORCED DRAUGHT ON MARINE-BOILER TUBES.

Mr. Geo. W. Dickie:—I should like to say a word or two in relation to the paper by Mr. Benbow on the application of forced draught in furnaces of marine boilers, and the defects of leaky tubes resulting therefrom.

Before doing so, however, I would like to express the sorrow I felt to hear the remarks made by Mr. Howden in regard to the possibility of economy with his system, in explaining some things relative to his paper.

I could see how closely our Chairman was attending to these remarks. It would not surprise me to find in the next specifications issued by the Bureau of Steam Engineering guarantees of consumption of fuel, added to that of speed and horse-power.

Referring to the matter of leaky tubes in the Scotch boilers which we had the misfortune to be connected with, and which, according to the newspapers, went to pieces, and came very near killing every one about, your humble servant included,—we found that any leakage that there was in the tubes was confined to the ordinary tubes; and so far as my experience goes in the application of forced draught, that has been the case in all vessels that we have had to do with. We have not yet found a leaky stay-tube. I do not know if this is the experience on the other side, but that is our experience; and I notice that Mr. Benbow has advocated a great many different types of tube-ends in order to overcome this difficulty, all of his propositions being virtually to convert the ordinary tube into a stay-tube. If it is a fact that the stay-tube gives no trouble, why not put them in all alike? I have thought a great deal about this matter, and I do not see any objection, if the stay-tubes are successful in resisting this tendency to loosen in the tube-plate, to fitting all the tubes in the same way. I should like to hear some discussion on this point.

Mr. F. B. King:—It seems to me that the explanation of the whole matter relating to tubes, as brought out, is to be found in the

fact that the stay-tubes have pulled the life out of the ordinary tubes. The contraction and expansion of the stay-tubes must be very different from that of the thinner tubes surrounding them, and in such a contest there is no doubt that the stay-tubes will have the victory.

MR. DICKIE:—In that case, Mr. Chairman, I want the survival of the fittest. We stay the other sheet in the combustion-chamber rigidly to the end of the boiler, all of the stays being screwed; and if the expansion and contraction of the stay-tubes does not affect the tubes themselves, then I want them all alike. I think it is a question that would admit of some experiment.

MR. E. PLATT STRATTON:—In this connection I would say that it was my province some years ago to operate a boiler of the Geo. H. Corliss type running in a steamship. It had, I think, six vertical cylindrical shells of 42 inches diameter, necked on at top and bottom to a central cylinder of 36 inches diameter, all of which were entirely surrounded by a brickwork furnace. These six vertical-cylinder boilers were full of 2-inch tubes 10 feet long. After several years of service I had occasion to renew these tubes throughout, and in doing so it was suggested to put in some stay-tubes, which would probably contribute to the efficiency and lasting properties of the others. Previously there was no trouble whatever with leaky tubes. They had given out at the upper end after several years of use. On putting in the new stay-tubes trouble began almost immediately, and continued until I took them out. With the former arrangement the expansion and contraction to each tube-sheet was comparatively uniform, but by putting in the stay-tubes with nuts on the ends I concentrated the strain on these particular tubes, producing leaks continually, which were probably also in a measure due to a lack of ability to keep the ends of these stay-tubes and nuts cool, the heat not being conducted off with sufficient rapidity. I think the same thing goes on in a great many boilers with stay-tubes, especially when you force combustion under them and bring an intense heat to bear on the thicker parts of the nuts and tubes in a way that it cannot be conducted off or absorbed.

MR. DICKIE:—I think that these remarks bear out what I want to assert—that the tubes should be all alike; that if it is necessary to have stay-tubes, they should be all stay-tubes; that if it is not necessary to have stay-tubes, they should be all ordinary tubes. The proposed tube ends in Mr. Benbow's paper make the ordinary tubes equal to stay-tubes.

MR. E. PLATT STRATTON:—I wish to take no exception to the

proposition of Mr. Dickie, but in the introduction of nuts incident to the stay-tubes you would very soon lack in ability to keep them cool. That is, the absorption of heat would be so great from the mass of these nuts, there would be too great a thickness of material.

MR. GEO. W. DICKIE :—Mr. Stratton has evidently misunderstood my proposition when he objects to the nuts on the stay-tubes. We are not fitting stay-tubes with nuts any more. The thread in the tube for the combustion-chamber end passes through the front tube-sheet, which is threaded for the large end, so that the tube is screwed tightly into the front tubesheet, also being a good fit in the back tube-sheet, and is then expanded like the ordinary tube, but not beaded.

MR. JOS. R. OLDHAM :—Out on the Lakes I think we have hardly a vessel running with a stay-tube in her boilers. It is true that the tubes are rather closely spaced, leaving but little room for water circulation and for cleaning; but I never heard of any sign of fracture, and never saw any great leakage resulting from such staying. The tubes are simply expanded in the ordinary manner, and we have never had an accident.

As regards stay-tubes, I should very much prefer to see all the tubes made stay-tubes, but without the nut. There is no necessity for the nut; a continuous thread only is required to properly secure the tubes at both ends. But may I say that there are hundreds of boilers carrying 160 pounds of pressure without a stay-tube in them.

MR. DICKIE :—The best practice to-day, and I think the practice that prevails with the United States Government in their boilers, is that of having no nuts on the stay-tubes,—the tubes screwed out into the front head and into the back head, and rolled into the back head and put somewhat as the other tubes are, and the objection to nuts does not apply in this particular case. In my own practice I have not used a nut on a stay-tube for twelve years.

MR. JOHN M. SWEENEY :—The question arising from this paper seems to be the effect of forced draught as causing tubes to leak; that is, it seems to me to be taken for granted that a boiler which under natural conditions will not show leaky tubes, if forced draft is applied to that boiler the tubes leak. Now, so far as I have heard or noticed, observations have been in the direction of an improvement in the method of tube-fastening to stop the leakings. Inquiries should be directed to the cause of the leakage—Why does the tube leak when the forced draught is put on,—not with natural draught? So far as can be understood here from the paper, a great deal of

force seems to be attached to the theory that cold air entering and striking the tubes creates the leakage. I cannot accept that proposition. I do not think that it is proven, because I do not think it is proven what the temperature of the tube-sheet is. In the paper which was read here yesterday, of Mr. Foley, there were some experiments trying to establish what the temperature of the tube-sheet was, or might be, at different thicknesses, tests being made on a small model for that purpose; but it was not conclusive: it was not clear how the plugs were put in, and it did not go on to a thinness of tube-sheet sufficient to discover how low a temperature could be found.

It seems to me that the question of leakage is answered indirectly in the paper itself. On page 4, at the bottom, it says: "In this latter type the difficulty is increased by the tubes having been placed in rows diagonally, so that, although the tubes are ¾ inch apart, there is only a clear space of ¼ inch between the vertical rows for the steam to escape upwards;" and again on another page: "Finally, a number of tubes were removed in vertical rows, to facilitate the circulation of the water, after which the trials, up to a limited indicated horse-power, were made successfully." I think there is the answer laid down. There is an axiom in the very suggestive work by C. Wye Williams on Heat, which announces that in boiler-construction it is better to have the water get to the plate in order to absorb the heat, than it is to have the heat applied to the outside of the plate. When you take a boiler that works properly, without leaky tubes, under certain conditions (say of natural draught), and undertake to increase the heat-units set free by forced draught in the combustion-chamber, and ask the plates of the boiler to transmit that additional amount of heat to the water, the water must get to the plate; if it does not do that, the plate gets hot, and if the tube-sheet gets hot and the flue-end gets hot, a leak is sure to follow. The remedy is to change the boiler design for forced draught, put in fewer flues and leave more room between them for circulation of the water, and, although the calculated heating-surface may be lessened, the actual evaporative capacity of the boiler will be increased. I know such cases as actual results.

I do not believe that when cold air is allowed to strike the flue-ends leaks ensue because the cold air contracts the hot flue or plate. I believe the temperature of the flue and plate is probably below that of the air. In my judgment, the air contact raises the temperature of the flue faster than the plate, so expanding the flue into the hole in the sheet, and straining the flue beyond its elastic limit, and

thus causes leakage. In our Western river boilers we used to have great trouble from burns and bags over the grate-surface. It will be understood that these boilers are externally fired. A deposit of scale sometimes accumulates on the inside of the plate and prevents that portion of the plate from being wet, which consequently gets hot, the internal pressure pushes the hot part of the plate out, and the bag results. It is possible to push this hot part back to position, and is sometimes done without stopping the boat or operation of the boilers, by placing a proper stand on the grates, the stand serving as a fulcrum, over which a lever is operated to push the hot part of the plate back to position ; but we now avoid these bags almost entirely by the use of a scale-pan, so called. The following description will explain it :

The device herewith shown is illustrated as placed in the bottom of an externally fired boiler, over the grates, and is known as a "scale-pan." It can be placed equally well over the crown-sheet of a fire-box boiler or over the top of a furnace, provision being made to clear the stays where necessary. The pan is made of, say, No. 14 B. W. G. sheet iron, about 5 feet long and generally 12 to 14 inches wide, suitable for admission through the manhole opening into the boiler. In the case illustrated the pan is curved to a radius 2 inches less than the radius of the sheet of the boiler, this curvature being made the narrow way of the pan. The sides are flanged up for a width of about 3 inches in order to slightly stiffen the pan, and to this flange are riveted two or three legs on each side, the legs being 2 inches long below the bottom of the pan and attached to the flange of the pan with one rivet, so that they may be turned to lie with the flange on the pan, thus facilitating removal or return through the manhole opening. The legs are made of No. 14 sheet iron, and only about 1½ inches wide, so that the amount of area in the end of the leg coming in contact with the sheet of the boiler is inconsiderable.

The placing of this pan as described will prevent scale accumulations on the sheet, but will cause accumulations within the pan itself. Indeed, if a punched washer or other foreign substance be placed on the boiler-sheet under the pan, before the boiler is closed and filled with water, it will invariably be found within the pan upon the opening of the boiler after use. One peculiar fact noted in the use of these pans is that more scale in weight seems to be taken from the boiler with the pan than from the same boiler, performing as nearly as can be the same evaporation, without the pan; which brings the query: What becomes of the scale and other matter received by the boiler? It is not the intention at this time

to enter into an exhaustive discussion as to how or why the washer or scale goes into the pan ; that will be taken up later. There is no patent on the "scale-pan," and any one troubled with bugged boilers will find it a boon indeed.

MR. JAMES HOWDEN :—Before making a few remarks on Mr. Benbow's paper, I would like first to say, in reference to the remarks made just by Mr. Sweeney in regard to injury to tops of furnaces from overheating, that there is no danger whatever with clean plating from the highest possible heat. I believe that the highest heat ever generated in a boiler-furnace could not injure a boiler-plate properly placed and clean, with water over it. The evaporation takes away the heat from the plate so quickly, that the temperature of the boiler-plates directly over the fire is not sufficient to injure them in the slightest degree.

It is possible, however, that plates may be so arranged that the evaporated products may not get away quite so quickly as is desirable. A vertical tube-plate, for example, is not so favorably situated as a horizontal plate ; but even a vertical tube-plate, if clean and the temperature kept steady, that is, not intermittent, will not be injured by the highest heat in any properly constructed boiler.

Coming now to Mr. Benbow's paper, he describes plans for preventing the leakage of tubes in boilers, a leakage which, you will find in reading his paper, he assumes as inseparable from the working of boilers with forced draught. Mr. Benbow also assumes there is only one mode of using forced draught, and that is the closed stoke-hold system as applied by the British Admiralty.

That tubes do leak by this system of working there is abundant evidence; and Mr. Benbow's paper is taken up with describing a very elaborate construction of tube-ends, which, if fitted in the tube-plates in the manner he proposes, would, he believes, keep the tube and tube-plate from separating under that effect of the high heat which, it is supposed, does the damage when using forced draught. I have already explained that with my system there has never been a drop of leakage found from a tube-end, even at the very highest power that could be forced out of the boiler, and this with tube plates of the ordinary thickness, without a ferule or any protection whatever. The tube-plates in my boilers have been always bored with an ordinary tool, and the tubes put in in the ordinary manner by fixing with a turn or two of a roller expander. The tube-boring, if I remember rightly, cost a penny a hole, and the tube-fixing another penny, which is not an excessive cost. Such tubes as those Mr. Benbow proposes to use to remedy an evil which should not exist would, with the fixing of them in the tube-plate,

1400 I.H.P., though their air-heating arrangement is not so high or so efficient as the style I am now using; but notwithstanding these deficiencies these boilers have given at sea with their ordinary firemen 24.7 I.H.P. per square foot of fire-grate—an efficiency or a rate of power per square foot of grate which has never been approached in any Admiralty four hours' trial with selected firemen and hand-picked coal.

I am now engaged upon three steamers for a foreign government in which each furnace, 3′ 6″ diameter, with fire-grate 5′ 6″ in length, is to give 500 I.H.P.; that is, 6000 I.H.P. from 12 furnaces. You must grant that this is an unusual power to take out of four single-ended boilers 13′ 6″ in diameter, being 26 I.H.P. per square foot of grate. There is, however, no difficulty in obtaining this, as has been already proved. It simply means a little higher air-pressure and a little higher air-heating than is now used in the American Line cargo-steamers, and that is simply arranged. Owing to the high economy of the system, it means only a rate of combustion under 40 lbs. per square foot of grate. I am aware that economy is looked upon in naval circles as a matter of small moment, the idea being that it is only for a short time a high power is required to be used; and they say, Let us drive in the coal: it matters not, if we get the power. This idea is, however, altogether wrong, for the more coal you put into the furnace with these cold-air systems the less power you get out of it, that is, the less power per pound of coal used. This is a very bad and unscientific mode of getting a high power. What is wanted is to get the greatest possible power with the least possible coal. My system affords the means of doing so with almost an equal economy at all rates of combustion. Now, in adopting a mode of obtaining a high power irrespective of economy, which I believe you do here as much as in England, you are defeating the very object you desire to attain, for the more you economize, the greater the power you can attain on the grounds I have stated in my paper. The course I am now following, of increasing the economy, at the same time serves the purpose of increasing the power, so that this 500 I.H.P. per 3′ 6″ furnace with a 5′6″ grate can be all the more easily obtained, because of the high economy in fuel.

In the written remarks of Mr. Ellis of Sheffield on my paper, forwarded after the conclusion of the Congress, which I have since had the opportunity of perusing, I find Mr. Ellis appears to hold the view that my system of forced draught, while very good for moderate rates of combustion, is not so well adapted as the suction draught which he advocates for high rates of combustion. This view of Mr. Ellis, for the reasons I have set forth in my paper, I

must hold to be entirely wrong, and that the opposite view is correct as regards the rate of combustion.

While it is quite true that with a very high power exerted by exhausting fans a high rate of combustion can be obtained by suction draught, it is also true that in the same boiler with my system, suitably arranged in the air admission and outlet details, an equal rate of combustion can be obtained with at least one fourth of the fan-power. There would be these further advantages with my system: (*a*) a greater saving of the waste heat of the fire gases with one fourth of the air-heating tube-surface; (*b*) a greater economy of fuel, arising from the superior utilization of the waste heat and the reduced proportional quantity of air admitted to the furnaces per unit of coal consumed; also, the absence of the cold-air admission necessary in Mr. Ellis's system; (*c*) saving of the largely increased space in the vessel required for the large fans placed over the boilers, as in Mr. Ellis's system; (*d*) saving the wear and tear of fan and fan engines inherent in Mr. Ellis's system from their working in highly heated gases, which must inevitably make these machines short-lived; (*e*) the greater comfort to the men employed in attending to the fan-power, saving them from the unavoidable heat always existing in a steamship over the boilers.

I am likewise compelled to dissent from Mr. Ellis's conclusion that "the more you push or force the air and gases through the boiler the more you increase your difficulties and troubles, whilst you have a clear course if you exhaust the gases by suction." Mr. Ellis in making this assertion gives no reasons whatever in support of it. As I have given, I believe, sufficient reasons in my paper in direct opposition to this view, I refer readers to what I have already written on this part of the subject. Mr. Ellis, in putting forward these ideas, appears to lose sight of the fact that the rapidity of the supply of air to the furnaces, on which the rate of combustion must depend, is due to the greater or less difference of pressure between the outlet or chimney end, and that at the ash-pits and furnace end, whatever mode is used; the area and passages between these two ends, also temperatures, being alike. Under equality in these two latter conditions the difference in pressures between the combustion-chambers and the smoke-boxes, whether suction-draught or pressure-draught is used, must be exactly alike to pass the gases from an equal quantity of fuel consumed, or, to state it still more correctly, to pass equal weights and temperatures of gases through in equal times.

In stating the case in this form for simplicity's sake, I am stating it more favorably for the suction-draught than it actually

should be, for, when the difference in pressures is equal in both cases the gases in the case of the suction-draught are under less pressure than that of the atmosphere, while with the pressure-draught the gases are under somewhat greater pressure than that of the atmosphere when working at a high rate of combustion. The higher the rate of combustion the greater becomes this difference in the pressures of the gases, descending further below the atmosphere with the suction-draught, and ascending further above with the pressure-draught.

The practical effect of this difference in actual internal pressure is, that the same weight or quantity of gases is in smaller volume in the pressure-draught boiler than in the other. This condition, as I have shown in my paper, makes the heating-surface more effective, as an equal amount of heat in the fire gases, from the same weight of coal consumed, is in smaller volume with the pressure-draught, and consequently passes more slowly and more easily through the furnaces, combustion-chambers, and tubes, and therefore gives up more heat per unit of coal consumed than is done with the larger volume and more rapid passage of the gases with the suction-draught.

Mr. Ellis still endeavors to show that, in similar boilers, an equal quantity and temperature of fire gases may exist in the combustion-chambers, or pass through the tubes; but that this quantity and temperature in the boiler using suction-draught will not impart nearly so much heat to the plating forming the combustion-chambers and tubes, as they will in the boiler using pressure-draught. If this idea of Mr. Ellis was correct, no stronger argument against the use of suction-draught could be found. Mr. Ellis fails to see that if the suction-draught prevents the heat to a large extent from being taken up by the heating-surface of the boiler, it must pass into the fan and be thrown by it into the chimney. The only other alternative on Mr. Ellis's view is, that with the suction-draught the combustion of the same quantity of fuel in a furnace gives off much less heat than when pressure-draught is used, and the combustion-chambers and tube-ends are thus saved by the suction-draught from injury.

This alternative, however, is equally bad for the reputation of the suction-draught. Mr. Ellis, therefore, in endeavoring to overturn my argument lands himself in a dilemma, with the usual uncomfortable consequence.

I must likewise take exception to Mr. Ellis's ideas regarding the necessary power required from the fans in handling the same weight of air and fire gases by the two systems. Mr. Ellis says I

forget that "a pound of air is but a pound, and the extra power required of the engine is only the trifle due to the greater size of the fan required for the volume, but the actual work due to the gases will be the same."

Mr. Ellis here assumes that the power required to work the fans in these radically different modes of supply is in proportion, or nearly so, to the weight of air supplied to the furnaces. The weight of the air supplied to the furnaces, however, is merely a secondary factor in determining the respective powers required for the fans in these two systems.

To prove this, let it be assumed for simplicity of calculation that an equal weight of, say, 20 lbs. of air is required for combustion per pound of fuel consumed by both systems, though it can be shown that less air is required with mine. Let two fans be used of same size to produce an equal combustion from two equal boilers, the one being worked by exhaustion on Mr. Ellis's plan, and the other by pressure on mine. To give a basis of calculation, let the quantity of air entering the furnaces of each boiler be 15,000 cubic feet per minute. At about 60° temperature or 13 cubic feet per pound this quantity gives a weight of air of 1154 lbs. per minute for each boiler. Let the air pass through the pressure-fan at above volume and weight, and the fan be of dimensions sufficient to pass the 15,000 cubic feet in 300 revolutions, that is, 50 cubic feet, and 3.846 lbs. per revolution.

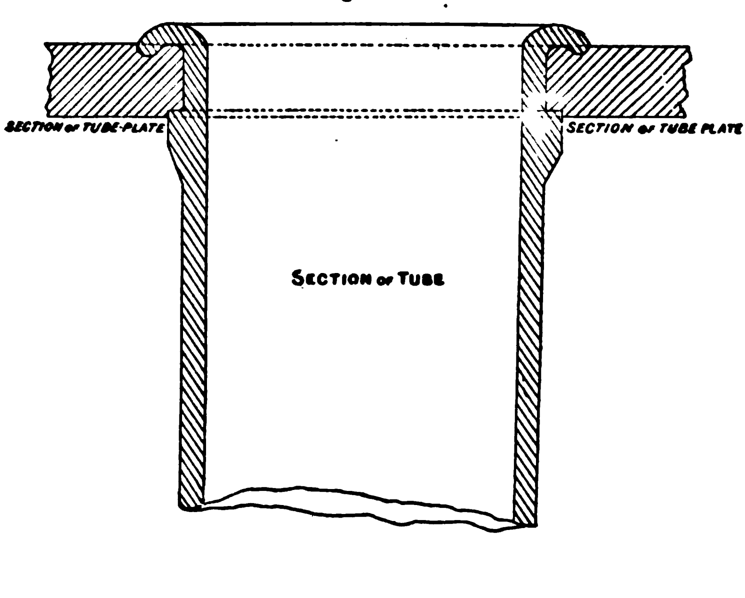
As the exhausting-fan has not only to pass through it these 1154 lbs. of air per minute in the fire gases, at the volume due to their temperature entering the fan, but also the weight of coal consumed, resolved into its gaseous products, it becomes necessary, in order to find how many revolutions this fan must make per minute to exhaust these products, to ascertain their volume at the temperature at which they enter the fan. I will assume the temperature of the gases entering the fan at 450° F.,—a temperature very probably below what will be found on board ship under even favorable conditions, when working at, say 20, I.H.P. per square foot of grate in boilers of ordinary proportions.

Taking, say, 10 lbs. of fuel without ash or sulphur, and with the following ordinary proportions of constituents in British coal:

Carbon	8.00 lbs.
Hydrogen	.55 "
Oxygen	.65 "
Nitrogen	.15 "
Moisture	.65 "

A proposed Method of Securing Boiler Tubes in Combustion Chamber Tube-Plate.

Fig. 11



XLIV.

MARINE-ENGINE VALVE-MOTIONS.

BY NATHAN P. TOWNE,

Chief Engineer, U. S. Navy; Consulting Engineer to the Wm. Cramp & Sons' Ship and Engine Building Company.

THE mathematics of the various valve-motions have been exhaustively treated by the many authors who have written on the subject, so that in this direction there remains almost absolutely nothing to be said, excepting what can be found elsewhere.

The question still asked among engineers is, Which gear is the best for the marine engine?

It appears to me that the answer to this question depends entirely upon the form of engine and the way it will "stow" to the best advantage in the space allowed for the machinery, which practically, in all cases of marine engineering, must be as small as possible.

This condition presents itself more strongly in the design of a war vessel than in those of the merchant service, where the engineer is practically unlimited as regards height, while in the former case the machinery must be below the danger-line of the enemy's fire. This condition has, until the introduction of the protective deck, compelled the engineers designing machinery for war vessels to use horizontal engines in unarmored ships.

Since the protection of the machinery has been assured, at least nominally, by the so-called protective-deck, the condition heretofore imposed upon the engineer has been modified to such an extent that he can use the vertical engine

(though of a limited height), with its many advantages, especially as regards fore and aft space in twin-screw vessels.

In the choice of valve-gear we are influenced principally by the length and breadth of the space assigned. If we have a narrow ship, twin-screw with large power, the position of the engines forced to the centre by the inclined protective-deck, we are almost compelled to use a valve between the cylinders, which condition forces us to the Stephenson link, taking more length which we can have, and using the breadth of the engine space for condensers and pumps. If, on the contrary, we are allowed breadth and height, or breadth alone, and desire to reduce our space fore and aft, we are forced to bring our cylinders as near as the length of bearings will permit, and place our steam-chests on the front of the cylinders.

Much has been said by the promoters of the different valve-gears as to their merits, and hosts of testimonials have been procured as to the superiority of each, but it would seem that the test of time has shown that the Joy, Hackworth, and Marshall-Bremme gears and the Stephenson link are equal, or nearly so; or, at all events, they are so nearly equal as to warrant the engineer, in designing an engine, being governed almost solely by considerations of room and cost of royalty. It seems ordinarily that a little shorter engine can be built with a Joy gear than with the others mentioned, as there is no length of shaft to be taken up by eccentrics; but this feature will be different in different engines, and can only be determined for individual cases. A reason against the employment of the Joy gear is the financial one of royalty, which of course, will influence the choice. As between the Hackworth and the Marshall-Bremme gear, the former gives the more even distribution of steam, owing to the pin on the eccentric-rod moving in a straight line instead of the arc of a circle, as is the case with the latter, but perhaps too much importance is attached to this feature. If either motion is used within proper limits, it is excellent; but when the attempt is made to "follow" too far, the angle of the radius rod or slide must be increased to such an extent that heavy stresses are brought upon the parts, and wreckage is almost sure to follow.

Other varieties of radial gears are coming up at various times, looking perfect on paper, but when put to the test of

trial on shipboard they have all been found wanting. One of the most promising of these, which has been used on locomotives in Europe for some time, the "Walschaert," was modified and used on H. M. S. "Australia," built by Messrs. Napier.

Its general principle was identical with that of all the radial gears, the motion of the valve being compounded of two other motions; one of them, which might be called the primitive valve-motion, being the same as that of a valve having neither lap nor lead, and another motion derived from a part which moves coincident with the piston and gives the lap and lead. This last motion is constant, and cannot be changed; while the other, or primitive motion, is variable in travel, but not in relative position to the piston.

In the "Australia," the primitive motion was regulated by the distance of a block from the end of the vibrating-link, and the lap-and-lead motion was obtained from a lever attached to the cross-head. This valve-motion, seemingly one of the most promising, was found wanting on the high-speed trial of the ship, on account of the inertia of the vibrating-link. Although it was not taken out of the ship, this gear has not been used in other vessels.

Many instances of this nature can be cited; and it requires a bold engineer to depart from one of the standard valve-motions until he can be assured of the success of the new one by a practical test. The restless brains of inventors cannot resist entering the field of valve-gear design, and we have in consequence numberless ideas put on paper and on engines. Some of these inventors do not seem to have any object in view other than a "pretty motion" or a different way of obtaining a motion that was well enough before. Others have in view the laudable objects of reducing the clearance, lessening the working parts or condensing the parts into a less space, or cheapness of construction.

There appears at certain periods a tendency all in one direction. At present there is a movement in favor of a shifting single eccentric, obtained in some cases by merely rotating the eccentric on the main shaft or on a geared counter-shaft, by means of a spiral groove in a bushing working on a feather, or by shifting the eccentric directly across the shaft. The latter has a constant lead and variable cut-off; the former allows only full gear forward and back, being merely a reversing-gear.

XLIII.

THE APPLICATION OF FORCED DRAUGHT TO THE FURNACES OF MARINE BOILERS, AND THE DEFECT OF LEAKY TUBES RESULTING THEREFROM.

BY HENRY BENBOW, D.S.O.,

Chief Inspector of Machinery, Royal Navy.

IN submitting for your consideration this paper on the application of forced draught to the furnaces of marine boilers, and the defect of leaky tubes resulting therefrom, I fully realize the responsibility I have incurred by undertaking to write upon so difficult and important a subject, as to which there exists such a diversity of opinion amongst the members of the engineering profession; and although the views herein expressed may not coincide with those held by many here present, I trust the points to which I am about to call attention may be considered of sufficient interest to warrant a fair discussion on your part.

Whether the arguments advanced are in favor of or against the views I have expressed, I feel certain some valuable opinions will be given and important information gained therefrom, tending to advance this difficult problem a step farther towards its final solution; and if such a result is obtained, I shall consider that my effort to this end has not been thrown away.

I propose, with your kind permission, to avoid all theoretical arguments,—as theory often sounds well, but fails when put in practice,—and will therefore confine myself entirely to the practical side of the question, pointing out some of the

advantages of the use of forced draught, and the difficulties we have experienced since its introduction, and how, in my opinion, these are to be reduced and, I hope, finally overcome.

The system of supplying air to furnaces of marine boilers under pressure, generally termed "forced draught," has many advantages; but, unfortunately, boilers as now constructed are not equal to the extra strain which its use entails; and, on this account, it is but seldom adopted in vessels of the mercantile marine. Our ship-owners, as a rule, prefer to retain the old and more reliable practice of fitting their ships with boilers large and numerous enough to generate sufficient steam, with the natural draught obtained by open stokeholds, and with, comparatively, a moderately low consumption of fuel per square foot of grate-surface, to work the auxiliary machinery on board, and drive the main engines at full speed; and, provided the coal used is of fairly good quality, and the down-draught to the stokehold adequate to support its proper combustion, the use of forced draught appears unnecessary. But, unfortunately, these favorable conditions cannot always be depended upon, as the coal purchased abroad is often of inferior quality, and when steaming in a calm, or with a moderate wind abaft, it is often impossible to obtain, with ordinary natural draught, the steam necessary to drive the engines at the required number of revolutions, and it is only by the incessant use of slice and pricker, with its consequent waste of fuel, that anything like a satisfactory result can be obtained.

I have frequently experienced a similar condition of things on board a man-of-war in the old days before the introduction of forced draught, and at the time regretted the absence of any mechanical means for increasing the draught to the furnaces; and no one who has not practically experienced the difficulty and labor often involved in keeping steam under these adverse circumstances can properly understand what a boon forced draught is to the firemen, for with it the difficulty of keeping steam is greatly reduced, as by simply increasing the air-pressure, when the fires and tubes become dirty. much of the hard work entailed by the constant use of slice and pricker is avoided.

In ships of war forced draught is now recognized as a

in each case. There can be no positive guide as to the stress on the stems of piston-valves, as it will vary with the adjustment of the packing; but, with the large factors of safety we use on such parts of the engine, it appears to be safe to take for a stress formula the following:

$$S = (R^2 \times W \times L \times .000341) + 5.6W.$$

For the "New York's" L. P. valve-stems, when $R = 138$, $W = 1500$, $L = 416$, we would have, with a stress of 6000 lbs. per square inch of section of rod, a diameter of about $1\frac{5}{8}$ inches; or with a stress of 4000 lbs. per square inch of section, a diameter of 2 inches.

Of course, for slide-valves the stresses will be larger, and the sizes of the valve-stems will be correspondingly increased.

The question as to the better form of valve to be used on triple-expansion engines seems to be undecided at the present time. The piston-valve for the high-pressure cylinder is almost universally used, but our English brethren seem to prefer in their latest designs the slide-valve for the intermediate and low-pressure cylinders, while we adhere to the piston-valve for all three.

The great advantage we have in the piston-valve is the diminution of friction, while in the slide-valve we diminish the clearance, have a tighter valve, and reduce the length of the engine, although not to any great extent, as the length of bearings will in most cases govern that feature.

There is a difficulty in designing the low-pressure valve to give a free exhaust and at the same time have sufficient steam confined in the cylinder to give enough cushion to prevent thumping on centres; but by using the excellent valve designed by Mr. Thom of Glasgow, this can be entirely overcome. The feature of this valve consists of opening a communication between the ends of the cylinder for a short time near the end of the stroke, admitting steam from the pressure end to the exhaust end, communication between that end and the condenser being already shut off.

In the high and intermediate pressure valves this object can be accomplished by negative lap, whereby the communication is established at the beginning of the exhaust at one end and before its closure at the other between the two ends

of the cylinder and the receiver, which will affect the cushion according to the sequence of the cranks. On a three-crank engine with the cranks 120 degrees apart, if the low-pressure crank leads, followed by the intermediate and high pressure, the cushion from negative lap will be greater than when the H.P. leads; as, in the former case, the steam has already been cut off in the succeeding cylinder, leaving the exhaust-steam to fill the receiver only, and thus increasing the back-pressure during the time both ports are open together.

It is usual to proportion the size of ports so as to give a velocity of steam through them which is based upon the maximum opening of port and the mean speed of piston. This velocity varies slightly in different designs, but it may be taken at from 100 to 125 feet per second through the high-pressure steam-port; from 125 to 150 through the intermediate ports; and from 150 to 175, and sometimes even higher, through the low-pressure ports, the velocity of the exhaust-steam being lower.

While, as a standard, this method of calculating velocities is no doubt well enough, yet it gives no idea of the true velocities of the steam through the ports. To a certain extent, the velocity of the steam from the exhaust-port of the cylinder immediately preceding the one under consideration should be taken as the velocity of the steam entering the cylinder, this, of course, depending upon the sequence of the cranks.

I give below a table of these two velocities taken at tenths of the stroke. The two sets of figures opposite each cylinder give velocities through the steam-port of the cylinder under consideration and through the exhaust-port of the cylinder from which the steam is exhausted, the former being in bold-faced type.

There is another difficulty which has occasioned considerable trouble in the use of piston-valves, and that is the packing. When springs are used, there is on the spring, or ring which is backed by springs, a varying pressure, which at one time is on the inside of the ring and at another on the outside, caused by the varying pressure in the cylinder. If this reverse pressure is balanced by the stiffness of the rings or by springs back of them, there will be a decided tendency to wear down the bridges across the ports more quickly than the

TABLE OF STEAM VELOCITIES.*

Name of Ship.	Piston Positions in Decimals of Stroke from Beginning.													
	Top or Outboard End of Cylinder.							Bottom or Inboard End of Cylinder.						
	.1	.2	.3	.4	.5	.6	.7	.1	.2	.3	.4	.5	.6	.7
Torpedo-cruiser:														
I. P. cyl.	220	282	317	337	360	408	573	198	270	321	381	445	581	2440
	120	153	172	183	214	294	573	105	147	170	192	263	446	2440
L. P. cyls.	......	1436	948	704	574	688	1920	......	1824	870	657	667	1570	
	188	230	278	344	448	688	1920	213	274	344	453	667	1570	
Cruisers 7 and 8:														
I. P. cyl.	219	287	326	340	360	547	1920	165	223	266	294	432	916	
	177	212	267	291	360	547	1920	114	152	206	284	432	916	
L. P. cyls.	......	......	1352	734	524	544	1369	......	1518	685	475	610	1825	
	157	204	233	285	363	544	1369	179	230	292	395	610	1825	
Vesuvius:														
I. P. cyl.	217	285	323	348	410	537	1109	183	251	298	318	350	584	3090
	202	245	285	337	410	537	1109	131	159	196	238	350	584	3090
L. P. cyls.	......	38620	3987	1377	794	914	4758	......	7788	1168	725	1056	4551	
	253	294	349	429	572	914	4758	267	334	434	601	1056	4551	
Philadelphia:	1631	801	583	421	391	502	886	608	417	380	364	353	455	1065
	211	244	286	330	391	502	886	128	157	185	234	295	455	1065
San Francisco:	675	393	329	281	295	407	936	558	302	261	332	562	1690	
	154	181	208	240	295	407	936	131	178	241	332	562	1690	

* In feet per second.

valve-liners in the body, causing a ridge at the end of the port, and in many cases tearing out the liner or breaking the ring. If the springs are not stiff enough, there will be a leaky valve. This we have sought to obviate, following the example of the valves on some of the Atlantic liners, by making the rings of the valves in one piece, divided at one point of the circumference only, and securing them by bolts so that, as the ring wears, a liner can be inserted in the joint sufficient to make the valve tight. This forms an adjustable plug-valve. On the H.P. cylinder in the large engines it is good practice, in my opinion, to use a plug-valve only, the leakage by it not causing much damage, as it has to pass through the intermediate and low pressure cylinders. Great care has to be taken in fitting these plug-valves, as the difference of expansion between the steam-chest casing and the valve will cause trouble. A good way is to move the valve by hand after the cylinder is heated, assuring a proper relation between tightness and friction.

Taking all of the advantages and disadvantages of the two classes of valves into consideration, it seems to be a good compromise to use, for triple-expansion engines, a single or double ported plug piston-valve on the high-pressure, a piston-valve packed as described on the intermediate-pressure, and either a double-ported slide or Thom piston-valve on the low-pressure cylinder.

It is well, in designing a valve-motion where an eccentric is used, to line the eccentric-strap with white metal, and, above all, not to be chary in width of eccentric.

DISCUSSION ON MARINE-ENGINE VALVE-MOTIONS.

MR. GEO. W. DICKIE:—I would like to call attention to the conclusions that Mr. Towne has come to or reasoned himself into in his paper, quoting from which he says: "Taking all the advantages and disadvantages of the two classes of valves into consideration, it seems to be a good compromise to use for triple-expansion engines a single or double ported plug piston-valve on the high-pressure, and either a double-ported slide or a Trick valve on the low-pressure piston."

I think in every design of engine that has gone through my hands for the Navy Department I have invariably advocated double-ported slide-valves, at least for the low-pressure cylinder. In one instance only were we successful in getting the Navy Department to sanction such, and that is the "San Francisco." At that time I think my friend Mr. Towne was the strongest opponent of the use of the slide-valve for any of the cylinders, and he took me very severely to task on that subject. I simply mention this to show that the adoption of the slide-valve on any of the cylinders by the Navy Department has come about very reluctantly and slowly. I understand that the designs now being prepared for the new vessels are to have slide-valves, both for the intermediate and low-pressure cylinders.

P. A. ENGR. FRANK H. BAILEY, U. S. N.:—In choosing a valve-gear two important points are to be considered. We should aim to get as simple a gear as possible, and one which will stand the wear and tear of service with the least liability to derangement. These points we consider to be of the greatest importance. We should also try to get a gear which will give a good distribution of steam and be economical of space. First cost should also be considered, but this is of far less importance than either of the other points. No gear is cheap which is liable to derangement, requires constant overhauling, or which does not give a satisfactory distribution of steam. The best distribution of steam is undoubtedly obtained by the use of separate steam and exhaust valves, but all such arrangements are so lacking in simplicity that they are seldom used on marine engines.

The Marshall-Bremme gear gives a fair distribution of the steam. It does not stand the test of actual use as well as the link, as is shown by the limited extent to which it is used. The Hackworth and Joy valve-gears give a beautiful distribution of steam for all grades of expansion. There is, however, one feature of these gears which is very unsatisfactory, and that is, a sliding link-block. Unlike the cross-head slides, which have the pressure always in one direction, and so do not rattle when loose, these blocks rub first on one side and then on the other, causing the gear to pound as soon as it has worn so as to have the least lost motion. A slide does not wear equally all over so that the faces remain true, but wears most in the middle, requiring its surfaces to be trued up from time to time, as well as to be set up in the usual way. In the Joy gear we have a curved slide, which is much harder to true up than a straight one.

The Stephenson link gives a good distribution of steam from about five-eighths to three-quarters of the stroke, but a poor one when we try to cut off shorter. It does not have the range which the other gears have. It is thoroughly reliable. When well designed the link-blocks remain nearly stationary in the link, and there is but little wear. There are no excessive stresses at any point, and no place where a little lost motion will seriously disarrange the movement of the valve. One of the strongest arguments in its favor is the persistency with which it holds its own against all-comers. This is exemplified in our own navy, where at one time the Marshall-Bremme gear was quite extensively used, but all the later designs of large engines made in the last two or three years have been fitted with the Stephenson double-bar link.

We are accustomed to speak of the piston-valve as a balanced valve, and one much easier to move than a slide-valve. So it is when made as a plug-valve or when fitted with solid rings and made of the right size. If, however, it is made, as is often the case, with cut rings, which press against the valve liner, it is far from frictionless. This feature brings up an interesting question. What pressure per square inch should the rings exert against the valve-chest liner. The greater the pressure, the more the friction and the greater the wear, especially on the bars across the ports. If this pressure is not made equal to or greater than the compression of steam in the cylinder, then when the ring is over the port during compression it will close up, allowing considerable leakage and causing unsatisfactory working, with a liability of breaking the rings. All of this is obviated when we adopt plug-valves or solid rings, but then the question of leakage comes up. How much is it? If not serious

when the engine is running at full speed, how is it when the engine is running slowly, as is the case with a man-of-war at ordinary cruising speeds? I would also ask, Is it safe to make one of these valves a neat fit, so it can just be moved by hand when the chest is warmed up with steam? Will the steam-pressure distort the chest appreciably, so as to cause the valve to bind, or would a little rust or dirt cause it to stick fast? I am afraid that most engineers in charge of ships would err on the side of too much leakage, rather than run the chance of having a valve stick and wreck the valve-gear. Some years ago Prof. Sweet invented a piston-ring which was made very stiff, but which was so constructed that, while it could not open beyond a certain amount, it could close up. It seems as if this is the right idea for a piston-valve ring. We could make it stiff enough either with springs or steam so it would not close up under compression, and we could make it as tight a fit as we thought desirable, for we would know that if too tight a little extra friction would be the only result until the ring had worn down to the right size. It would, in short, have all the advantages of a solid ring without its defects.

XLV.

THE SCREW-PROPELLER.

By SYDNEY W. BARNABY, Esq.,

M. Inst. C.E. and M.I.N.A.

DURING the last fifteen years our knowledge on the subject of screw-propulsion has been considerably extended. For some forty years after the introduction of the screw as a propeller by Ericsson and Smith in 1836, but little progress was made towards any such appreciation of its properties as would enable suitable proportions of pitch, diameter, and surface to be assigned for given conditions with any degree of precision.

Innumerable variations were made in the shape, number, and disposition of blades, and at a comparatively early stage a form was arrived at which was probably not far from the best. Latterly, attention has been directed chiefly, not to improvements in form, but to the determination of suitable dimensions; and it is along this line that a great and important advance has been made.

Although not ignorant of the excellent work done in this field of research by American engineers, I propose to deal exclusively with the investigations carried on in England, because I suppose that, as this is a congress in which representatives of all nations take part, each contributor is expected to bring forward the work of his own country.

It is now established that for every different ratio of pitch to diameter there is a particular slip-ratio at which, and at which only, maximum efficiency can be obtained.

Thus, it has been ascertained experimentally, that in the case of a screw of a particular standard form, the real slip, as measured by pitch multiplied by revolutions, at different pitch-ratios should be of the amount given in Table I in order to obtain the best results.

At any other slip-ratio than these, the efficiency will be less than the maximum.

It may be interesting to describe the means by which these important results have been reached. They were foreshadowed in 1878 by the late Mr. Froude, who deduced by theory curves of thrust, horse-power, and efficiency similar to those afterwards obtained by experiment.

The method adopted by Mr. Froude and also by Mr. Thornycroft, who was working independently in the same direction, was as follows:

A screw, having what I have referred to as a "standard" form, was caused by an external apparatus to progress at a constant speed through undisturbed water. By rotating it at different velocities any desired amount of slip was obtained.

For example, suppose a propeller of one foot pitch is made to advance through the water at the rate of 400 feet per minute. If it be made to rotate 400 times a minute the slip will be *nil*, and will increase at different rates of revolution up to 50 per cent at 800 revolutions per minute.

By measuring the thrust exerted by the screw and the power expended in rotating it at different revolutions, it was ascertained at what particular amount of slip that screw gave the best return for the work expended upon it.

Treating in this way a number of screws differing only in pitch-ratio, the real slip proper to each, as given in Table I, was obtained.

By thus separating the performance of the screw from that of the vessel, all disturbing elements are eliminated, and I consider that the following conditions may be laid down as essential, if the results obtained from screw experiments are to be useful for general application:

1. Each screw must be tried at a number of slip-ratios.

2. The velocity of feed must be capable of accurate measurement.

3. The power expended in driving the screw must be measured, and it must be the power given out by the shaft, and not complicated with engine friction, which is an unknown quantity.

This being admitted, it follows that no experiments would be satisfactory in which the screw under examination is working behind a vessel, because of the difficulty of measuring the

forward motion of the frictional wake, and the consequent uncertainty as to the true velocity of feed.

It would be possible thus to ascertain the most suitable propeller for the vessel upon which the experiment was carried out, or for a vessel of similar form, with screws similarly situated. It would, indeed, be the best way of so doing; but it would be difficult to apply such information as might be obtained to the purpose of designing a screw for a vessel of a different form.

When we know the real slip, proper for a screw of a given pitch-ratio, then it is necessary to examine the ship which is to be propelled and the engines which are to supply the power, and to estimate as nearly as we can the probable mean speed of the frictional wake and the power absorbed by internal friction in the engines. We are then in a position to definitely fix upon the diameter, pitch, and revolutions which will insure that the screw shall have that amount of real slip which we desire.

I have placed in an appendix a table I have compiled from a complete set of experiments made by Mr. R. E. Froude, together with an explanation of the method of using it.

It is possible by means of it to design a screw which shall have maximum efficiency under any given conditions of I.H.P. and speed; or, if revolutions or diameter are so limited as to preclude the adoption of the most suitable dimensions, those may be selected which will be the best under the given conditions, and the efficiency at once ascertained, provided only that the engine efficiency is not abnormal, and that the designer can correctly estimate the reciprocal influences of the hull and the screw.

It is still the fashion among a certain number of engineers to describe the screw-propeller as something which no one can understand—as subject either to laws or to caprices which have eluded discovery; but whatever truth may once have been in the statement, it is in my opinion true no longer, and is but the convenient excuse of men who lack the necessary leisure to make themselves acquainted with the progress which has been made, and with the work done by Messrs. Froude, Thornycroft, Greenhill, Blechynden, Fitz Gerald, Calvert, and others. That there is without doubt great difficulty in hitting off at once the best screw for a vessel, is to be

gradually, is not advisable, as it causes unequal expansion of the tubes and tube-plate. The tubes directly over this furnace have been known in consequence to commence leaking, and to take up again soon after the other fires were lighted

5. Every care should be taken to exclude, if possible, oil or grease from the interior of the boiler.

6. After steaming, the fires should be allowed to die out, and the furnace and ashpit doors kept closed, if practicable, until the boiler has cooled down.

DISCUSSION ON EFFECT OF FORCED DRAUGHT ON MARINE-BOILER TUBES.

MR. GEO. W. DICKIE:—I should like to say a word or two in relation to the paper by Mr. Benbow on the application of forced draught in furnaces of marine boilers, and the defects of leaky tubes resulting therefrom.

Before doing so, however, I would like to express the sorrow I felt to hear the remarks made by Mr. Howden in regard to the possibility of economy with his system, in explaining some things relative to his paper.

I could see how closely our Chairman was attending to these remarks. It would not surprise me to find in the next specifications issued by the Bureau of Steam Engineering guarantees of consumption of fuel, added to that of speed and horse-power.

Referring to the matter of leaky tubes in the Scotch boilers which we had the misfortune to be connected with, and which, according to the newspapers, went to pieces, and came very near killing every one about, your humble servant included,—we found that any leakage that there was in the tubes was confined to the ordinary tubes; and so far as my experience goes in the application of forced draught, that has been the case in all vessels that we have had to do with. We have not yet found a leaky stay-tube. I do not know if this is the experience on the other side, but that is our experience; and I notice that Mr. Benbow has advocated a great many different types of tube-ends in order to overcome this difficulty, all of his propositions being virtually to convert the ordinary tube into a stay-tube. If it is a fact that the stay-tube gives no trouble, why not put them in all alike? I have thought a great deal about this matter, and I do not see any objection, if the stay-tubes are successful in resisting this tendency to loosen in the tube-plate, to fitting all the tubes in the same way. I should like to hear some discussion on this point.

MR. F. B. KING:—It seems to me that the explanation of the whole matter relating to tubes, as brought out, is to be found in the

fact that the stay-tubes have pulled the life out of the ordinary tubes. The contraction and expansion of the stay-tubes must be very different from that of the thinner tubes surrounding them, and in such a contest there is no doubt that the stay-tubes will have the victory.

Mr. Dickie:—In that case, Mr. Chairman, I want the survival of the fittest. We stay the other sheet in the combustion-chamber rigidly to the end of the boiler, all of the stays being screwed; and if the expansion and contraction of the stay-tubes does not affect the tubes themselves, then I want them all alike. I think it is a question that would admit of some experiment.

Mr. E. Platt Stratton:—In this connection I would say that it was my province some years ago to operate a boiler of the Geo. H. Corliss type running in a steamship. It had, I think, six vertical cylindrical shells of 42 inches diameter, necked on at top and bottom to a central cylinder of 36 inches diameter, all of which were entirely surrounded by a brickwork furnace. These six vertical-cylinder boilers were full of 2-inch tubes 10 feet long. After several years of service I had occasion to renew these tubes throughout, and in doing so it was suggested to put in some stay-tubes, which would probably contribute to the efficiency and lasting properties of the others. Previously there was no trouble whatever with leaky tubes. They had given out at the upper end after several years of use. On putting in the new stay-tubes trouble began almost immediately, and continued until I took them out. With the former arrangement the expansion and contraction to each tube-sheet was comparatively uniform, but by putting in the stay-tubes with nuts on the ends I concentrated the strain on these particular tubes, producing leaks continually, which were probably also in a measure due to a lack of ability to keep the ends of these stay-tubes and nuts cool, the heat not being conducted off with sufficient rapidity. I think the same thing goes on in a great many boilers with stay-tubes, especially when you force combustion under them and bring an intense heat to bear on the thicker parts of the nuts and tubes in a way that it cannot be conducted off or absorbed.

Mr. Dickie:—I think that these remarks bear out what I want to assert—that the tubes should be all alike; that if it is necessary to have stay-tubes, they should be all stay-tubes; that if it is not necessary to have stay-tubes, they should be all ordinary tubes. The proposed tube ends in Mr. Benbow's paper make the ordinary tubes equal to stay-tubes.

Mr. E. Platt Stratton:—I wish to take no exception to the

proposition of Mr. Dickie, but in the introduction of nuts incident to the stay-tubes you would very soon lack in ability to keep them cool. That is, the absorption of heat would be so great from the mass of these nuts, there would be too great a thickness of material.

MR. GEO. W. DICKIE :—Mr. Stratton has evidently misunderstood my proposition when he objects to the nuts on the stay-tubes. We are not fitting stay-tubes with nuts any more. The thread in the tube for the combustion-chamber end passes through the front tube-sheet, which is threaded for the large end, so that the tube is screwed tightly into the front tubesheet, also being a good fit in the back tube-sheet, and is then expanded like the ordinary tube, but not beaded.

MR. JOS. R. OLDHAM :—Out on the Lakes I think we have hardly a vessel running with a stay-tube in her boilers. It is true that the tubes are rather closely spaced, leaving but little room for water circulation and for cleaning; but I never heard of any sign of fracture, and never saw any great leakage resulting from such staying. The tubes are simply expanded in the ordinary manner, and we have never had an accident.

As regards stay-tubes, I should very much prefer to see all the tubes made stay-tubes, but without the nut. There is no necessity for the nut; a continuous thread only is required to properly secure the tubes at both ends. But may I say that there are hundreds of boilers carrying 160 pounds of pressure without a stay-tube in them.

MR. DICKIE :—The best practice to-day, and I think the practice that prevails with the United States Government in their boilers, is that of having no nuts on the stay-tubes,—the tubes screwed out into the front head and into the back head, and rolled into the back head and put somewhat as the other tubes are, and the objection to nuts does not apply in this particular case. In my own practice I have not used a nut on a stay-tube for twelve years.

MR. JOHN M. SWEENEY :—The question arising from this paper seems to be the effect of forced draught as causing tubes to leak; that is, it seems to me to be taken for granted that a boiler which under natural conditions will not show leaky tubes, if forced draft is applied to that boiler the tubes leak. Now, so far as I have heard or noticed, observations have been in the direction of an improvement in the method of tube-fastening to stop the leakings. Inquiries should be directed to the cause of the leakage—Why does the tube leak when the forced draught is put on,—not with natural draught? So far as can be understood here from the paper, a great deal of

force seems to be attached to the theory that cold air entering and striking the tubes creates the leakage. I cannot accept that proposition. I do not think that it is proven, because I do not think it is proven what the temperature of the tube-sheet is. In the paper which was read here yesterday, of Mr. Foley, there were some experiments trying to establish what the temperature of the tube-sheet was, or might be, at different thicknesses, tests being made on a small model for that purpose; but it was not conclusive: it was not clear how the plugs were put in, and it did not go on to a thinness of tube-sheet sufficient to discover how low a temperature could be found.

It seems to me that the question of leakage is answered indirectly in the paper itself. On page 4, at the bottom, it says: "In this latter type the difficulty is increased by the tubes having been placed in rows diagonally, so that, although the tubes are $\frac{3}{4}$ inch apart, there is only a clear space of $\frac{1}{4}$ inch between the vertical rows for the steam to escape upwards;" and again on another page: "Finally, a number of tubes were removed in vertical rows, to facilitate the circulation of the water, after which the trials, up to a limited indicated horse-power, were made successfully." I think there is the answer laid down. There is an axiom in the very suggestive work by C. Wye Williams on Heat, which announces that in boiler-construction it is better to have the water get to the plate in order to absorb the heat, than it is to have the heat applied to the outside of the plate. When you take a boiler that works properly, without leaky tubes, under certain conditions (say of natural draught), and undertake to increase the heat-units set free by forced draught in the combustion-chamber, and ask the plates of the boiler to transmit that additional amount of heat to the water, the water must get to the plate; if it does not do that, the plate gets hot, and if the tube-sheet gets hot and the flue-end gets hot, a leak is sure to follow. The remedy is to change the boiler design for forced draught, put in fewer flues and leave more room between them for circulation of the water, and, although the calculated heating-surface may be lessened, the actual evaporative capacity of the boiler will be increased. I know such cases as actual results.

I do not believe that when cold air is allowed to strike the flue-ends leaks ensue because the cold air contracts the hot flue or plate. I believe the temperature of the flue and plate is probably below that of the air. In my judgment, the air contact raises the temperature of the flue faster than the plate, so expanding the flue into the hole in the sheet, and straining the flue beyond its elastic limit, and

thus causes leakage. In our Western river boilers we used to have great trouble from burns and bags over the grate-surface. It will be understood that these boilers are externally fired. A deposit of scale sometimes accumulates on the inside of the plate and prevents that portion of the plate from being wet, which consequently gets hot, the internal pressure pushes the hot part of the plate out, and the bag results. It is possible to push this hot part back to position, and is sometimes done without stopping the boat or operation of the boilers, by placing a proper stand on the grates, the stand serving as a fulcrum, over which a lever is operated to push the hot part of the plate back to position ; but we now avoid these bags almost entirely by the use of a scale-pan, so called. The following description will explain it :

The device herewith shown is illustrated as placed in the bottom of an externally fired boiler, over the grates, and is known as a "scale-pan." It can be placed equally well over the crown-sheet of a fire-box boiler or over the top of a furnace, provision being made to clear the stays where necessary. The pan is made of, say, No. 14 B. W. G. sheet iron, about 5 feet long and generally 12 to 14 inches wide, suitable for admission through the manhole opening into the boiler. In the case illustrated the pan is curved to a radius 2 inches less than the radius of the sheet of the boiler, this curvature being made the narrow way of the pan. The sides are flanged up for a width of about 2 inches in order to slightly stiffen the pan, and to this flange are riveted two or three legs on each side, the legs being 2 inches long below the bottom of the pan and attached to the flange of the pan with one rivet, so that they may be turned to lie with the flange on the pan, thus facilitating removal or return through the manhole opening. The legs are made of No. 14 sheet iron, and only about 1½ inches wide, so that the amount of area in the end of the leg coming in contact with the sheet of the boiler is inconsiderable.

The placing of this pan as described will prevent scale accumulations on the sheet, but will cause accumulations within the pan itself. Indeed, if a punched washer or other foreign substance be placed on the boiler-sheet under the pan, before the boiler is closed and filled with water, it will invariably be found within the pan upon the opening of the boiler after use. One peculiar fact noted in the use of these pans is that more scale in weight seems to be taken from the boiler with the pan than from the same boiler, performing as nearly as can be the same evaporation, without the pan; which brings the query: What becomes of the scale and other matter received by the boiler? It is not the intention at this time

The thrust delivered by the curved guides amounts to about one third of the whole thrust. Forward of the cylinder and keyed on to the shaft are screw blades of the same radius as the cylinder, whose function is to propel when going astern. They are of the same pitch as the leading edge of the turbine propeller blades, and advance through the water without propelling when the vessel is going ahead. When the vessel goes astern, these blades receive water, not only through the turbine cylinder, but also from outside it. The speed of any vessel for a given number of revolutions is always much less when going astern than when going ahead, so that, when the engines are reversed, the blades throw a stream of water forward and thus propel the vessel astern. If we compare the screw turbine with the propeller shown in Fig. 1, it will be seen that, instead of occupying, as that does, a very short length of the contracting column, the whole contraction is forced to take place within the length of the cylinder. The column enters it at the speed v and leaves at the speed $v + s$. The efficiency, therefore, neglecting friction, is equal to that of the ideal screw, $\dfrac{v}{v + \frac{s}{2}}$. As the surfaces are large, the efficiency is reduced by friction to about the same as that of the best ordinary screw, over which, however, it has this advantage, that, as there is no suction in front of the cylinder, there is no augmentation of hull resistance.

The chief value of the propeller lies in the fact that its maximum efficiency is obtained with a very high slip-ratio.

Thus, while the thrust at maximum efficiency of an ordinary three-bladed screw of one foot diameter, as ascertained by our model experiments, was 12 lbs., the thrust of a screw turbine of the same diameter and equal efficiency was 26½ lbs., while that of another of the same diameter, but of longer pitch and rather less efficiency, was as high as 32 lbs. The same thrust and efficiency can, therefore, be obtained with a screw turbine as with an ordinary screw of much larger diameter, and it is, therefore, especially adapted to vessels of light draught. To give an example: we have propelled vessels, 140 ft. × 21 ft. × 2 ft. draught of water, at 15¼ knots an hour, with two 32-inch screw turbines.

If ordinary screws had been employed, they must have

been 54 inches in diameter to have run at the same number of revolutions per minute, and given the same thrust, an increase of 69%.

The efficiency would have been a little greater, as the screw turbines were worked at rather more than their proper slip-ratio.

Fig. 5 shows an arrangement of the screw turbine suitable for ferry-steamers. The stern-way screw being placed in the bow, is in the most favorable position for propelling and steering astern. It has been found, that when vessels have had screws at each end, both of which took part in propelling ahead, the resistance has been largely increased by the action of the forward screw. Mr. Isherwood* has estimated the augmented resistance caused by the bow screw of the "Bergen" to amount to 23½%; but with a screw-turbine at the stern doing the whole work going ahead, and a stern-way screw at the bow advancing without slip, no water would be thrown against the vessel, and the resistance would not be increased.

I will conclude by briefly summarizing the progress of the last fifteen years, which I have endeavored to describe in the paper.

It has been established:

(*a*) That there is a definite amount of real slip at which, and at which only, maximum efficiency can be obtained with a screw of any given type, and that this amount varies with the pitch-ratio. The slip-ratio proper to a given ratio of pitch to diameter has been discovered and tabulated for a screw of a standard type.

(*b*) That screws of large pitch-ratio, besides being less efficient in themselves, add to the resistance of the hull by an amount bearing some proportion to their distance from it, and to the amount of rotation left in the race.

(*c*) That the best pitch-ratio lies probably between 1.1 and 1.5.

(*d*) That the fuller the lines of the vessel, the less the pitch-ratio should be.

(*e*) That coarse-pitched screws should be placed further from the stern than fine-pitched ones.

f. That apparent negative slip is a natural result of abnormal proportions of propellers. That it can probably be pro-

* Journal of A. S. N. E., August, 1890, p. 251.

duced in any vessel by a suitable selection of diameter, pitch, and revolutions, but will always be accompanied by waste of power. That it is brought about by two conditions in combination, neither of which would be sufficient of itself to produce it: first, the existence of a frictional wake; second, the fact that a screw blade dismisses the water at a higher speed than its own as measured by pitch and revolutions; that, in short, the slip of the water is greater than the slip of the screw, so that there may be sufficient real slip in the race to enable its backward momentum to be equated to the forward momentum of the vessel, and yet the apparent slip of the screw may have a negative value.

g. That three blades are to be preferred for high-speed vessels, but, when the diameter is unduly restricted, four or even more may be advantageously employed.

h. That an efficient form of blade is an ellipse having a minor axis equal to four tenths the major axis.

i. That the pitch of wide-bladed screws should increase from forward to aft, but a uniform pitch gives satisfactory results when the blades are narrow, and that the amount of the pitch variation should be a function of the width of the blade.

j. That a considerable inclination of screw shaft produces vibration, and that, with twin screws turning outwards, if the shafts are inclined at all, it should be upwards and outwards from the propellers.

APPENDIX

Let it be supposed that the resistance of a vessel at a given speed is known—say by measuring the pull in the tow-rope.

In order to propel the vessel at this speed by means of a screw at the stern, a thrust will have to be exerted by the screw greater than the pull of the tow-rope by an amount varying with the pitch-ratio and position of the propeller, and which may be assumed for the present purpose at 10%.

As the screw works in a forward current produced by the friction of the vessel, its speed through the water will be less than the speed of the vessel by an amount varying very much under different circumstances. The velocity of this current

will depend upon the length of the ship, the form of the lines, the state of the bottom, and the position of the propeller.

Let us assume that it is 10% of the speed of the vessel; in other words, that the velocity of feed is 10% less than the ship's speed.

Again, the indicated horse-power of the engines will exceed that transmitted to the screw by an amount equal to the power expended in internal friction. This ratio may be taken as I.H.P. : power in shaft : : 100 : 77.

Finally, taking the mean efficiency of the propeller at 65 per cent we have all the elements necessary to enable us to fix the dimensions of a screw to work behind a ship at the real slip suitable to its pitch-ratio.

Now, thrust horse-power or T.H.P. = thrust of screw × velocity of feed.

Effective horse-power or E.H.P. = tow-rope resistance × speed of ship.

If we agree to assume tow-rope resistance = thrust × .9, and velocity of feed = speed of ship × .9, then T.H.P. = E.H.P.

Since I.H.P. is greater than E.H.P. by the amount wasted by the friction of the engine and by the screw, using the assumed values of these losses, we get

$$\text{E.H.P.} = \text{I.H.P.} \times .77 \times .65;$$

$$\therefore \frac{\text{E.H.P.}}{\text{I.H.P.}} = .5 = \text{propulsive coefficient.}$$

These assumptions were made by Mr. R. E. Froude, in his paper of 1886,* from which the above has been condensed, and I have adopted them in constructing the constants in Table II.

The values of C_A and C_R in that table are obtained from the model trial results at any slip-ratio as follows:

Let thrust of screw in pounds............... $= T$;
velocity of feed in knots per hour........ $= v$;
speed of ship $\left(= v \times \frac{1}{.9}\right)$............... $= V$;
revolutions per minute.................. $= R$;
disk area of model in square feet......... $= A$;
diameter of model in feet............... $= D$;
$\frac{Tv}{33000} \times 2 \times 101$........................ = I.H.P.

* Trans. Inst. Naval Architects, XXVII, p. 250.

Then

$$C_A = \frac{A \times V^3}{\text{I.H.P.}};$$

$$C_R = \frac{R \times D}{V}.$$

Allowance can be made for different values of wake percentage by multiplying the speed of ship V by the corresponding wake factor given in Table III.

A correction can also be made for any deviation from the assumed value of propulsive coefficient. If, for example, it is desired to take this at .6 instead of .5, the I.H.P. must be multiplied by the ratio $\frac{.6}{.5}$.

Again, the constants are suitable for four-bladed screws; they can be used for three-bladed or two-bladed screws by multiplying the I.H.P. by $\frac{1}{.865}$ or $\frac{1}{.65}$, respectively.

EXAMPLES IN THE USE OF TABLES.

Example 1.—Find the diameter and revolutions of a screw to work at maximum efficiency for a vessel of 20 knots speed and 6000 I.H.P., pitch-ratio to be 1.2.

The disk area constant (C_A) in the table for this pitch-ratio is 288.

The revolutions constant (C_R) in the table for this pitch-ratio is 92.

$$\text{Disk area} = C_A \times \frac{\text{I.H.P.}}{(\text{speed in knots})^3} = 288 \times \frac{6000}{20^3} = 216 \text{ sq. ft.}$$

$\therefore$ Diameter = 16.5 feet. Four blades.

$$\text{Revolutions} = C_R \times \frac{\text{speed in knots}}{\text{diameter in feet}} = 92 \times \frac{20}{16.5} = 111.$$

Example 2.—Find the pitch and revolutions of a screw to work at maximum efficiency for a vessel of 20 knots speed and 6000 I.H.P. Diameter not to exceed 15.5 feet. To have four blades. Disk area = 189 sq. ft.

$$C_A = 189 \times \frac{20^3}{6000} = 252.$$

Nearest disk area constant in table, under maximum efficiency, is 251 at pitch-ratio 1.0.

$$\therefore \text{ pitch} = 15.5 \text{ feet.}$$

The corresponding value of C_R is 109.

$$\therefore \text{ Revolutions} = 109 \times \frac{20}{15.5} = 141.$$

Example 3.—Find the pitch-ratio and efficiency of a four-bladed screw for a vessel of 20 knots speed and 6000 I.H.P. The diameter to be 15.5 feet and the revolutions about 80 per minute.

$$\text{Disk area} = 189 \text{ feet};$$

$$C_A = 189 \times \frac{20^3}{6000} = 252;$$

$$C_R = 80 \times \frac{15.5}{20} = 62.$$

The nearest constants in table are at pitch-ratio 2.2 and efficiency 68 per cent.

Example 4.—Find the diameter and pitch of a screw to work at maximum efficiency for a vessel of 20 knots speed and 6000 I.H.P. Revolutions to be 85. Correction to be made for a wake percentage of 16.

The multiplier from Table III is 0.94.

$$20 \times 0.94 = 18.8 \text{ knots.}$$

By trial and error it will be readily found that the constants 306 and 85 for disk area and revolutions, respectively, at 1.3 pitch-ratio, will give the required number of revolutions. Thus:

$$306 \times \frac{6000}{(18.8)^3} = 276 \text{ sq. ft.}; \quad \therefore D = 18.95 \text{ ft.},$$

and

$$85 \times \frac{18.8}{18.75} = 85 \text{ revolutions, nearly.}$$

Example 5.—Find the diameter, pitch, and revolutions of a three-bladed screw to work at maximum efficiency for a vessel of 20 knots speed and 6000 I.H.P., pitch-ratio to be 1.2.

$$C_A = 288; \quad C_R = 92;$$

$$6000 \text{ I.H.P.} \times \frac{1}{0.865} = 6940;$$

$$288 \times \frac{6940}{20^3} = 250 \text{ sq. ft.}; \quad \therefore D = 17.8 \text{ ft.};$$

$$92 \times \frac{20}{17.8} = 103 \text{ revolutions};$$

$$\text{pitch} = 17.8 \times 1.2 = 21.3 \text{ ft.}$$

Example 6.—Find the diameter, pitch, revolutions, and efficiency of a four-bladed screw to work with apparent negative slip, for a vessel of 20 knots speed, 6000 I.H.P., and 10% wake. At 0.8 pitch-ratio and 63% efficiency,

$$C_A = 468; \quad C_R = 122;$$

$$468 \times \frac{6000}{20^3} = 351 \text{ sq. ft.}; \quad \therefore \text{diameter} = 21.12 \text{ ft.};$$

$$\text{pitch} = 21.12 \times 0.8 = 16.9 \text{ ft.};$$

$$\text{revolutions} = 122 \times \frac{20}{21.12} = 115.$$

If the product of the C_R constant multiplied by its proper pitch-ratio is greater than 101.33′, the apparent slip will be positive; if less, it will be negative. The amount of the slip in either case will be given by

$$\text{slip per cent} = \frac{pC_R - 101.33'}{pC_R} \times 100,$$

where

$$p = \text{pitch-ratio}.$$

The apparent negative slip of the screw in Example 6 would be

$$\frac{0.8 \times 122 - 101.33'}{0.8 \times 122} \times 100 = 3.8\%.$$

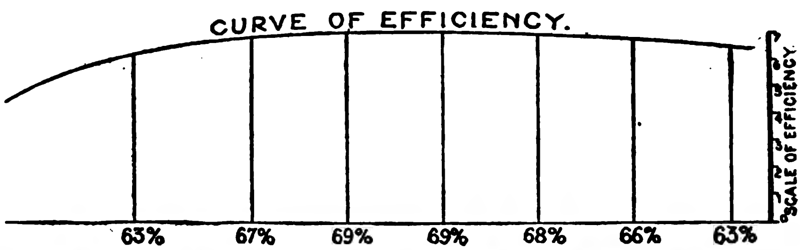
No correction has been made in Table II for the reduction of efficiency due to increase in pitch-ratio, as the amount is uncertain.

As stated in the text, pitch-ratios between 1.1 and 1.5 should be preferred, and between these limits the efficiency is not greatly affected by race rotation.

TABLE I.

Pitch-ratio.	Real Slip of Screw.	Pitch-ratio.	Real Slip of Screw.
.8	15.55	1.7	21.3
9	16.22	1.8	21.8
1.0	16.88	1.9	22.4
1.1	17.55	2.0	22.9
1.2	18.2	2.1	23.5
1.3	18.8	2.2	24.0
1.4	19.5	2.3	24.5
1.5	20.1	2.4	25.0
1.6	20.7	2.5	25.4

TABLE II.



Pitch-ratio.	C_A	C_R	C_A	C_R	C_A	C_R	C_A	C_R	C_A	C_R	C_A	C_R	C_A	C_R
0.80	468	122	304	128	215	134	157	142	115	150	86	160	65	171
0.90	506	109	329	114	234	120	170	127	125	135	93	144	71	154
1.00	546	99	355	104	251	109	184	115	135	123	100	131	76	140
1.10	585	91	380	95	270	100	196	105	144	113	107	120	82	128
1.20	625	83	405	87	288	92	210	97	154	104	115	111	87	119
1.30	665	77	431	81	306	85	224	91	163	97	122	103	93	111
1.40	704	72	456	76	325	80	236	85	173	90	129	97	98	104
1.50	741	67	482	71	342	75	250	79	183	85	136	91	104	98
1.60	780	63	507	67	360	71	263	75	193	80	144	87	109	93
1.70			533	63	378	67	276	71	202	76	151	82	115	88
1.80			558	60	396	64	290	68	212	73	159	78	120	84
1.90			584	57	415	61	304	65	222	69	166	75	125	81
2.00			609	55	432	58	315	62	231	67	173	72	131	77
2.10			635	52	450	56	329	59	241	64	180	69	136	75
2.20			660	50	469	54	342	57	250	62	187	67	142	72
2.30			685	48	486	52	355	55	260	59	194	64	148	69
2.40			710	47	505	50	369	53	270	57	202	62	153	67
2.50			736	45	523	48	381	52	280	56	209	60	159	65
	5		7		9		11		13		15		17	

Scale of Abscissa Value.

Disk area $= C_A \times \dfrac{\text{I.H.P.}}{(\text{Speed in knots})^3}$; Revolutions $= C_R \times \dfrac{\text{Speed in knots}}{\text{Diameter in feet}}$.

$$\text{Disk area} = C_A \times \frac{\text{I.H.P.}}{(\text{Speed in knots})^3}$$

$$\text{Revolutions} = C_R \times \frac{\text{Speed in knots}}{\text{Diameter in feet}}$$

TABLE III.

Wake Percentage.	Multiplier for Wake Correction.	Wake Percentage.	Multiplier for Wake Correction.	Wake Percentage.	Multiplier for Wake Correction.
0	$\frac{1}{.90}$	7	$\frac{1}{.97}$	18	.92
				19	.91
1	$\frac{1}{.91}$	8	$\frac{1}{.98}$	20	.90
				21	.89
2	$\frac{1}{.92}$	9	$\frac{1}{.99}$	22	.88
				23	.87
3	$\frac{1}{.93}$	10	1.	24	.86
		11	.99	25	.85
4	$\frac{1}{.94}$	12	.98	26	84
		13	.97	27	.83
5	$\frac{1}{.95}$	14	.96	28	.82
		15	.95	29	.81
6	$\frac{1}{.96}$	16	.94	30	.80
		17	.93		

The Screw Propeller by S. W. Barnaby.

Fig. 1.

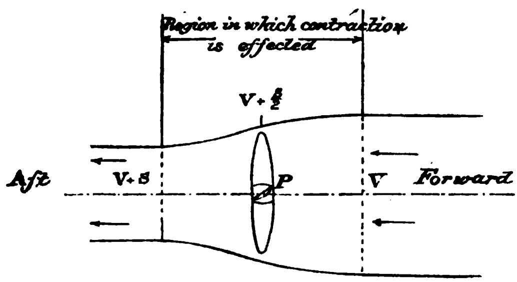
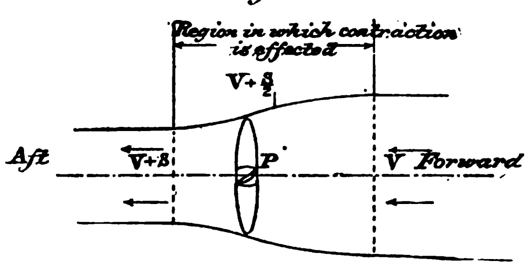


Fig. 2.



FIGS. 3 AND 4.

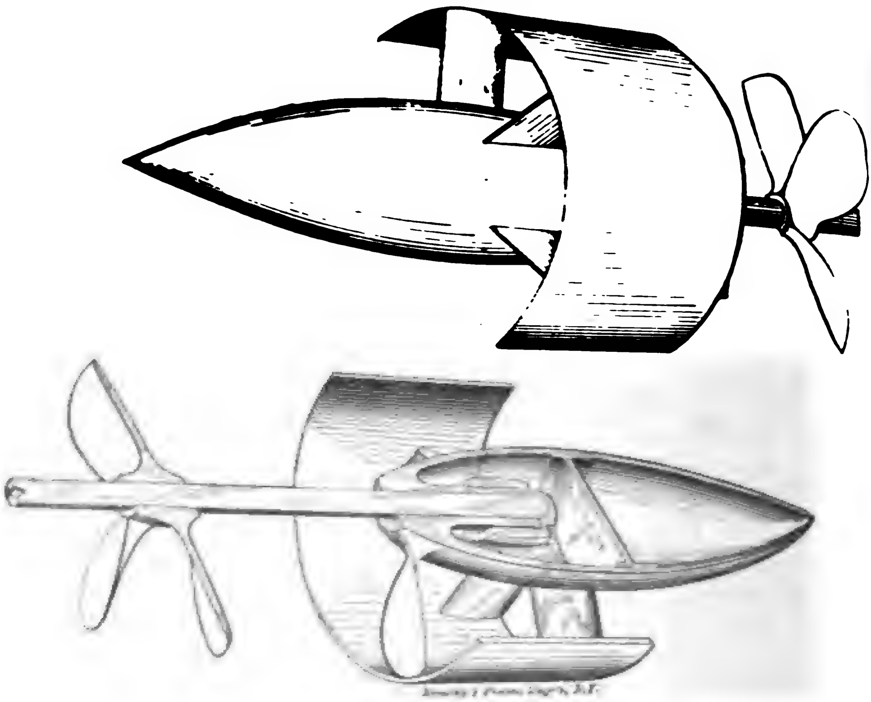
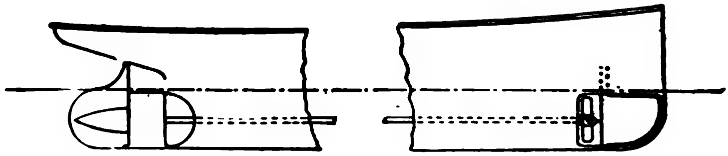


Fig. 5.



DISCUSSION ON THE SCREW-PROPELLER.

SECRETARY MCFARLAND:—I want to call attention to the fact that Mr. Barnaby, as most of us know, although still a young man, is an authority on this subject. He has had unusual opportunities for acquiring information in regard to propellers, because he took part in the very extended series of tests made by Mr. Thornycroft, so that I feel that the paper represents very much more to us than just so many pages of interesting matter. It is written in very simple fashion, and gives results that we can depend on as being the matured experience of this gentleman, as based on all his own experiments and all that he has been able to learn about propellers, so that where he gives certain data, for example, certain ratios, as the best to adopt in the screw-propeller, we can feel that we are very safe in adopting them.

MR. JOHN C. KAFER:—I followed some of Mr. Barnaby's advice in designing a propeller and then added more surface. After repeated trials it was found that it was necessary to have about twice the calculated surface. It was a short-stroke engine, and the revolutions ran up to very nearly 300. I took as a basis the propeller of the "Cushing;" the engines developed about the same power with same revolutions. When running up to 300 revolutions with a propeller very much in excess in pitch, larger in diameter, and a great deal more surface than the "Cushing's" propeller, I could not get more than half the indicated horse-power on the engine that there was developed and shown on the "Cushing." I was confronted with a problem of how to get the speed out of the boat. The only way we could do was to increase the surface of the propeller, and I did that two or three times, until I finally made the propeller with as much surface as was possible to get on to hold the engine down in revolutions and develop the power. Now in the "Cushing" there is approximately 20 per cent slip, at about 300 revolutions, and I think, developing about 600 horse-power. The propeller, with an increased pitch and surface, ran off 300 revolutions with about 350 horse-power. The difference lay in the boats. One was rather a hard boat to drive; the "Cushing" was an easy, fine-lined boat; so

that any rule that may be formulated for a propeller for any particular kind of vessel would not hold good with a vessel of entirely different shape or different displacement. In considering the propeller to be used in a particular vessel, the type of vessel must be considered as well as the speed. I think there is no way of getting accurate data other than by collating it and forming a kind of common, "horse sense" opinion on the subject. There are certain conditions in building up a propeller that we must follow, and in doing that I think the first is experience with propellers working under similar conditions.

COL. E. A. STEVENS:—I want to ask a question, simply in the hope that Mr. Barnaby, in the discussion of the subject, may be able to answer it. I notice on page 11 he speaks of the application of the screw-turbine to the ferry-boat, and there quotes some measurements made by Chief Engineer Isherwood as to the resistance caused by the bow-screw of the "Bergen." Some of you may be familiar with the experiment. The "Bergen" was docked and one of her screws taken off, the remaining screw pulling and then pushing; and I may say briefly, that the increase of resistance was about what would have been expected from the increased friction of the water delivered from the screw which was at the head of the vessel. The question may be asked, What is the use of introducing that increased element of resistance? The reason for it is a twofold one. In the harbor in New York we are troubled occasionally with ice,—not of course to the extent that some of you gentlemen are familiar with on the Lakes, but with ice which is a serious impediment to a side-wheel vessel. A side-wheel vessel is utterly unable to clear its slip of ice. We found that tug-boats fastened to the ferry bridge and then backed violently into the slip would clear the ice out of the slip. Then after the vessels were built it was found that the manœuvring power was so much greater with screws than with paddle-wheels, and all the time that can be saved on a ferry is of importance. Screw ferry-boats are the quickest-stopping vessels I know of. In such a crowded harbor as New York, and with a close margin of time, there are great advantages in being able to maintain speed till very close to the ferry bridge, and then stop your vessel with very great ease. I want to ask whether, in Mr. Barnaby's opinion, that stopping power would not be to a great extent sacrificed by this screw-turbine arrangement. The screw at the stern is inefficient as a backing instrument. We have tried it, having broken propellers on some of the boats, and run them with only one screw. You have to give them a very large margin, so much so as to impair their efficiency in backing. As I understand Mr. Bar-

naby's sketch, his ferry-boat would have to reverse ends every trip, or sacrifice backing power in one direction.

MR. HOWDEN:—I would like to say a few words on this subject, having studied it considerably, but on account of Mr. Barnaby not being present, and the fact that my conclusions on the subject are entirely opposed to his, I have some hesitation in stating such directly opposed views in his absence, as I feel as if it were taking him at a disadvantage. Having, however, come several thousand miles to attend the Congress, I can scarcely allow this discussion to pass without saying a word or two.

Mr. Barnaby says in the last two paragraphs of the first page: "It is now established that for every different ratio of pitch to diameter there is a particular slip-ratio at which, and at which only, maximum efficiency can be obtained." "Thus it has been ascertained experimentally, that in the case of a screw of a particular standard form, the real slip, as measured by pitch multiplied by revolutions, at different pitch-ratios should be of the amount given in Table I in order to obtain the best results." I must entirely dissent from these conclusions, and that it is established that these things are as there stated, because the table on which these conclusions are based has been got up from experiments that could give no proper indication of the actual work of a screw in propelling. In the second page Mr. Barnaby describes the kind of experiments from which the table was got up. He says: "It may be interesting to describe the means by which these important results have been reached. They were foreshadowed in 1878 by the late Mr. Froude, who has deduced by theory curves of thrust, horse-power, and efficiency similar to those afterwards obtained by experiment."

Mr. Barnaby then goes on to describe the method adopted by Mr. Froude and Mr. Thornycroft to ascertain the thrust, horse-power, and efficiency of propellers. This was done by revolving a small screw on a shaft in the bow of a steam launch which was at the same time driven by an independent screw in the stern of the vessel in the usual manner, the bow-screw acting merely on a dynamometer. I may use this sketch of a boat already drawn on the blackboard to illustrate how the propellers were placed. [Sketch made showed a launch with a screw in the stern in the usual manner, and at the other end a small screw below water-line, carried clear of the bow, with its shaft entering the boat.] The propeller in the stern drove the boat, and was regulated to give a uniform speed of 4½ knots. The small propeller in the bow, from the performances of which this table was formed, was only 9

inches in diameter and 10.25 inches pitch. You will find the particulars in Mr. Barnaby's paper, read before the Institution of Civil Engineers in London in 1890.

The table was got up from data found in this way: With the launch being driven at 4½ knots by the propelling screw, when the small model screw was driven a little over 500 revolutions per minute the speed of the model screw was in unison with that of the launch, and consequently made no slip. The very delicate dynamometer, which was in connection with the model screw forward, accordingly showed then little or no thrust. From this it was concluded by Mr. Barnaby that a propeller that made little slip was a very bad propeller, and of low efficiency. I must say I could scarcely have believed that such a conclusion could have been reached by any practical man, or one that had studied the working of the propeller. As the model screw was not propelling, but merely running in unison with the speed of the boat,—this is, the pitch × revolutions being then equal to the speed of the boat,—there could be no thrust, as it was doing no work further than overcoming friction in running the shaft and screw at the revolutions. When the speed was increased so as to make considerable slip—that is, running about 700 or 800 revolutions, the boat still being propelled at 4½ knots—the speed of the model screw × pitch into revolutions was then from 6 to 7 knots, so that all above 4½ knots was spent in slip and churning the water. The thrust from this slip at the higher speeds is necessarily indicated on the dynamometer, but this does not show that the model propeller is of higher efficiency because it was thus made to indicate more thrust. Mr. Barnaby, however, concludes that when so recording greater thrust on the dynamometer he is obtaining greater efficiency out of his screw at those revolutions, though all the while it was doing no work practically, and could not by such means indicate whether the screw was good, bad, or anything else; it merely showed the work done in churning the water and making a large slip. If you read the paper I mentioned, you will find that not only does Mr. Barnaby make these conclusions from the thrust of the model screw, but credits the model with the work done by the propelling screw, as the thrusts obtained from the model screw are multiplied into the 4½ knots speed done by the other screw, and called the "useful work." From the results obtained by such experiments rules and tables have been made, to which Mr. Barnaby directs your attention as affording means of finding proper proportions of screws for all kinds of steamships.

It has been to me a most remarkable thing that rules and tables

got up in such a way should have been printed and also discussed by engineers without any one but myself having ever pointed out the erroneous basis on which they have been formed.

There is another point in Mr. Barnaby's paper which could scarcely be passed without remark. In the second paragraph of page 4 it is said: "It is now acknowledged that the water is influenced by a screw before it is actually in contact with it, and will run towards a screw in virtue of a defect of pressure or suction produced forward of it." Then he says in the same paragraph, farther down: "Mr. R. E. Froude has shown what would be the action of an ideal propeller which may be assumed to produce no rotation." So far from these statements or claims being proved to be correct, they can without much difficulty be proved to be entirely wrong. Take this statement, for instance, about the water running towards a screw—that is, from the forward side. This idea is founded on the assumption that the screw is not a screw, but a pump, being itself stationary, as it were, as regards the water outside of its influence, but drawing the water on which it acts towards itself, and after carrying it round throws it off at a high velocity. This you will find explained in the paper of Mr. R. E. Froude, who is the principal idealist on this subject.

These notions, it appears to me, have originated in this way: In the making of a propeller all these gentlemen, I am sure, will show the geometry of the propeller's construction correctly; but when they come to the propeller's action in the water they leave geometry and conceive some ideal movements and effects, which they treat as facts without any proof whatever of their correctness, and on these supposed movements they build their theories. Of course, if you grant their premises as correct, a formula can be founded thereon which will work out a conclusion mathematically correct, though quite wrong in point of fact. The conclusion can only be correct when the premises are correct; but when they are wrong no algebra in the world will produce therefrom a correct conclusion. If you keep strictly to your geometry in regard to the action of the propeller when at work in the water, then you are safe; for a screw is a definite instrument in size and proportions, and with a given velocity through the water and ascertained slip a correct geometrical delineation of its movement and work can be made, which will keep you right as to the knowledge of its action. As soon, however, as you leave geometry and take to ideal notions about a screw forming a column in itself, which it works round like a wheel and throws astern, you will get out of your depth entirely, and, in fact, on to ground altogether imaginary.

Now, to prove this, suppose I take this as a section of a blade at a given diameter, as on this view of the blade [sketching on black-board] (see Figs. 1 and 2). I find I have shown a left hand propeller. This is its line of motion through the water with the slip, and this is the line of motion of its propelling face in turning on its axis if without slip, and these its lines of motion in turning it with, say, 10 per cent slip (see Fig. 1). If the screw is working without slip, then the line of the propelling face moves through the water as a straight line, and gives no motion to it whatever in going round. Now, the idea which seems to prevail in most minds holding the notion of columns of water drawn into the propeller as into a kind of suction pump with a side delivery, is that it moves round its axis in this manner—that is, generating planes at right angles to its axis (see Fig 1), and so draws in the water at its forward side and drives it astern from its after side. This it would do if the propeller was not moving forward with the ship as well as revolving, as the lines of its motion would be as here shown. Now, instead of this inducing pumping action, all the motion this propeller can impart to the water in propelling is the slip, whatever it may be, of the whole revolution, divided by the number of times the breadth of this blade here divides the whole length of the line it makes in its revolution; it may be a twentieth or a thirtieth only of the slip of the whole revolution. Supposing we had a propeller making 10 per cent slip: the lines made by the two extremities of this section of the blade would be as on the diagram; the two ends of the circumferential line describe two parallel lines at very little distance from each other; the distance between these parallel lines is the measurement of the motion given to the water by this blade at 10 per cent slip. This is the motion which a proper application of geometry to the movement of a blade in water shows is produced with a given slip.

To show now more fully that a screw driving a ship is not a pump, let us remove this section of the blade and place it so (see Fig. 3), where it is seen moving continuously through the water, as it does in reality when making the assumed 10 per cent slip. A section of a blade on any circumferential line is just like a half-model of a ship which, if propelled in a continuous straight course with its flat side lying slightly at an angle, as shown in this sketch, would act exactly as any circumferential section of a propeller-blade with equal slip. When we see a propeller turning in the water in relation to the horizontal plane of the surface of the water, or any other plane, we see its spiral circular motion in regard to that plane; but as regards its actual motion in relation to the water, as

it passes through it, keeping its movement to any fixed plane out of view, a section of any circumferential line of a screw-blade has exactly the same motion through the water, and the same action on the water, as the immersed part of the half-ship model has, moving straightly and continuously, as represented in this diagram.

Taking this section of a screw-blade (Fig. 3) in its motion through the water as a half-model of a ship, it would never occur to any one that the model or its bow end was sucking the water towards it. No more does the section of a screw-blade or its leading edge suck or draw the water towards it. The screw-blade cuts its way through the water in exactly the same manner as a ship does. I hope I have made it plain that an immersed blade passing edgeways through the water has simply the same action as that of a ship cleaving the water. When we get rid of the idea of the fixed plane in relation to the screw's movement the fact of the continuous motion of the blade through the water becomes quite easily understood. I regret to say that the supposed actions of a screw which are being published at the present time in papers like this are entirely misleading. They are not based upon facts, but on ideas resting on no foundation.

If you will look at Figs. 1 and 2 on the last page of Mr. Barnaby's paper you will find the propeller is there shown as acting like a pump on the water, which it throws behind in a great stream. If any one, studying the geometry of the propeller's action, will just keep to the geometry, I will have no fear of their failing to arrive at a proper conclusion regarding the screw's action.

DR. FRANCIS ELGAR:—Mr. Howden referred to the disadvantage we are under, and that he felt, in discussing a paper in the absence of the author, and not being able to have his reply; but I understand that reports of the discusion will be sent to the authors of papers who are absent, in order that their replies may be obtained in writing, for publication in the Report of our Proceedings. I would like to ask, sir, if this be so; and if Mr. Barnaby will not therefore have an opportunity of replying to the discussion upon his paper.

SECRETARY MCFARLAND:—Dr. Elgar is exactly right. It has been our intention from the start to send to every author who is not present the complete stenographic report of all remarks in the discussion of his paper, so that, if he so desires, he can make reply.

MR. H. B. ROELKER:—The propellers which are in question are real turbine-pumps. Those which are described on the last pages of Mr. Barnaby's book on marine propellers, as made by Mr. Thornycroft with Mr. Barnaby's coöperation, would for a 30-inch

diameter have something like $2\frac{1}{2}$ or 3 feet entering pitch, increasing to about 8 feet, or even greater leaving pitch.

The slip in these propellers must have been 60 or even 70 per cent, and they are actually pumps throwing out water aft, and they have an especial provision for turning the stream of water from the whirling motion into which it gets, to one moving directly aft or nearly so by stationary guiding blades attached to the vessel aft of the propeller.

MR. ALFRED BLECHYNDEN (contributed by mail):—The thanks of all engineers are due to Mr. Barnaby for the work he has done in attempting to elucidate a very difficult and important subject, and to put the experimental data of Mr. Froude into such a form as to be practically and readily serviceable in the everyday work of designing screw-propellers for steam-vessels.

There are, however, many points in his paper which are subject to criticism, and there is no reason why such should not be given in a fair and open spirit, with the object of bringing the matter to a more certain bearing.

This is my object in the following remarks.

It is assumed by the author that to ensure maximum mechanical efficiency of propulsion it is necessary to select a screw as a propeller, of such proportions as will work with the power required for propulsion at that slip-ratio which has been found by the trials of small model screws in still water to correspond with maximum efficiency. This is, however, an assumption, as I have already pointed out in a paper read before the Northeast Coast Institution of Engineers and Shipbuilders in 1891, which is not supported by an analysis of the trials of steam-vessels.

The chief advantages which have resulted from the trials of model screws have been, first, the determination of their mechanical efficiency and quantitive values of the thrusts corresponding with different speeds and slip and pitch ratios, and the power required to work the models under such conditions; and, secondly, by induction, the thrusts, powers, and efficiencies of screws of other dimensions, when working under similar conditions.

That the powers developed on screws when fitted as propellers upon ships correspond with those calculated from the data supplied by model experiments, has been shown by a series of examples in the paper already mentioned. These experiments are, however, those made by me in 1882.

But when we come to consider the problem of the determination of the screw-propeller which shall result in maximum mechanical propulsive efficiency, experience shows that while the model

trials furnish data which are an important if not a necessary auxiliary in the investigations, they are not directly serviceable, and a knowledge of the mechanical efficiency of the screw *per se*, although interesting and otherwise valuable, need not, in the present condition of our knowledge of the subject, enter into the solution of the problem.

I have referred to mechanical efficiency of propulsion in contrast to commercial efficiency, which is a problem as much more complicated than mechanical propulsive efficiency, as the latter is over screw efficiency *per se*. This commercial propulsive efficiency is the problem which the designer has ultimately to consider, the question being one involving matters of maxima and minima, and is a series of compromises with the view of securing the highest result on the credit side of the balance-sheet.

If it be supposed that we start from the zero position of the screw's efficiency curve, and continuously vary the conditions so as to move along the axis of abscissæ towards the highest ordinate, we shall commence with a screw indefinitely large compared with the power to be developed upon it, but by increase of slip the size will decrease. We may suppose also, as appears to be the case, that with the decrease in diameter the sucking action of the screw will decrease. Then it may just be that when the screw is made of such a size as to work with the slip of maximum screw efficiency the sucking action may be greater than if its diameter were reduced, in which case propulsive efficiency would continue to increase with decrease of diameter so long as the decrement of the sucking action due to any decrement of diameter exceeded the effect of the decrement of the screw's efficiency; and again, supposing the screw of maximum mechanical propulsive efficiency having been determined, commercial efficiency might be augmented by still further decreasing its diameter and mechanical efficiency until the benefit following decrease in cost and weight of the engine by reason of its greater speed of revolution were balanced by the cost of and the loss of paying freight displaced by the extra coal consumed due to the decrease of mechanical propulsive efficiency.

It has been laid down as a principle that the only means of determining the efficiencies of, and power required on, a given screw is by model trial or otherwise by actual experiment, and that the only sure means (except by the trial of the actual hull itself) of determining the resistance of a given form of vessel is by trial of its model at a speed corresponding to that intended in the ship itself, so also, I venture to say, the only way to determine the pro-

pulsive efficiency of any screw used as a propeller is by trial on the vessel or its equivalent.

Now, the great advantage of model trials is their having put such an equivalent in our hands, or, in other words, they have enabled an equivalent already in our hands to be utilized.

A sufficiently extensive series of accurate trial results in steam-vessels might have served to determine the propeller of maximum propulsive efficiency for each type of ship and screw, but it would have involved such labor and cost that the task would have been practically hopeless.

Now, a systematic series of model trials of screws of different pitch-ratios and at varying slip-ratios has supplied the means of calculating the dimensions of a screw of any given pitch-ratio within the limits of the experiments, which shall work with the same thrust and slip at the same speed and power as one of another pitch-ratio; and being thus provided, it becomes possible to analyze a series of trials of vessels of a similar type, and to compare the propulsive efficiency of each relatively to the size or comparative size of a screw of standard type and pitch-ratio, and so, assuming the series of vessels to have propellers of a sufficiently great range of proportions, to determine with what size of screw of that standard type maximum propulsive efficiency is obtained on that type of vessel, and at that equivalent speed. Having once determined this, it is not necessary that the vessel should be fitted with that particular standard screw to insure the best results; but what may be called an *equivalent screw*, or, in other words, one upon which the required power can be developed with approximately equal advance and slip.

To illustrate these views I shall give a series of trial results of full, cargo vessels of approximately one type, corresponding speeds, and with propellers of about one pitch and surface ratio. They are, moreover, mostly vessels with machinery built by one firm, at about one time, so that the results may be considered as being little disturbed by difference in excellence of workmanship and design. They are arranged in the order of the increasing value of the ratio of augmented surface to the screw's disk area, and the coefficient of performance in relation to the augmented surface is in each case placed beside this ratio. The values of $\frac{(\text{Displacement})^{\frac{2}{3}} \times \text{Speed}^3}{\text{I.H.P.}}$ are not given, as varying much more considerably with slight change of form than the other.

The first case in the table is a vessel of a type differing from the rest, and it is fitted with a screw of a much smaller pitch ratio.

Ref. No.	Length, Feet.	$\frac{\text{Length}}{\text{Beam}}$	Prismatic Coefficient.	$\frac{\text{Speed}}{\sqrt{\text{Length}}}$	$\frac{\text{Wetted Surface}}{\text{Disk}}$	$\frac{\text{Augmented Surface}}{\text{Disk}}$	$\frac{\text{Augmented Surface} \times V^3}{\text{I.H.P.}}$	$\frac{\text{Pitch}}{\text{Diameter}}$	Remarks.
1	149.25	6.66	.638	.6	35.6 51.3	44.8 64.7	16600	1.25 .895	Single-screw compound
2	320	9.02	.725	.62	74.	87.9	19900	1.290	Ditto
3	275	7.34	.730	.634	68.	89.5	19300	1.240	Ditto
4	270	7.72	.750	.624	78.2	95.0	20100	1.265	Ditto
5	260	7.76	.778	.611	79.1	100.0	20600	1.23	Ditto
6	270	7.56	.762	.642	80.5	104.0	20920	1.23	Ditto
7	285	7.91	.785	.579	86.6	110.6	20600	1.19	Ditto
8	285	7.7	.752	.590	84.6	107.1	20000	1.23	Ditto
9	300	8.10	.786	.605	94.1	119.0	21250	1.26	Ditto
10	300	8.10	.785	.620	94.0	119.0	23500	1.26	Ditto
11	317	8.49	.762	.619	97.8	119.4	23800	1.23	Ditto
12	338.5	8.5	.710	.628	103.5	125.0	23900	1.25	Ditto
13	285	7.5	.800	.609	97	127.9	22750	1.254	Ditto
14	285	7.5	.800	.600	98.	128.9	24900	1.254	Ditto
15	330	8.92	.764	.6125	103.	130.0	24900	1.27*	Ditto
16	285	8.15	.764	.615	112.	140.0	22800	1.25	Ditto
17	338.5	8.5	.720	.622	125.5	152.0	22350	1.25	Ditto
18	232	6.12	.800	.600	115.	170.0	16600	1.25	Twin-screw triple

* About.

The ratios of the surfaces are given both for the true disk area and for that of an equivalent screw of 1.25 pitch ratio; it would not, however, necessarily be a screw of exactly the same efficiency. This vessel is much finer than the others, as indicated by its prismatic coefficient, and its coefficients of performance are consequently greater than they should be for proper comparison in this table.

Now if the figures under $\frac{\text{Augm'd surf.}}{\text{Disk}}$ and $\frac{\text{Augm'd surf.} \times V^3}{\text{I.H.P.}}$ be compared, the broad general fact will become evident that the propulsive efficiency increases gradually with reduction of the screw's size relatively to the hull until it has become about $\frac{1}{130}$ of the augmented surface, after which there is a marked decrease of efficiency with decrease of relative disk area.

The preceding might be considered ample evidence on this point, but the following table, while not so direct, is strong support. The vessels are of the same class, but their relative speeds are in some instances a little lower and vary from .55 to $.63 \times \sqrt{\text{length of vessel in feet}}$; as, however, the resistance varies approximately as the square of the speed over that range for this type of vessel, the difference affects the comparison but slightly. The pitch ratios of the actual screws are also somewhat finer, being about

1.1 to 1.15, as against 1.25 in the preceding series; in order, therefore, that the comparison may be fair, the size of an equivalent screw of 1.25 pitch ratio has in each case been calculated and the vessels have been summed up in groups. The machinery of all were manufactured by one and the ships built by another company.

Type of Engine.	Number of Vessels.	$\frac{\text{Augmented Surface}}{\text{Disk Area of Equivalent Screw.}}$	$\frac{\text{Augm't'd Surface} \times V^3}{\text{I. H. P.}}$	Actual Pitch Ratio.
2 cylinder compound...............	2	83.0	19200	1.10
Triple.	2	98.7	18800	.991
2-cylinder compound...............	6	103.6	20530	1.136
Three 2 cylinder compound, Two triples, ...	5	115.3	20922	1.118
2-cylinder compound...............	2	127.2	22325	1.135
One triple, One 2-cylinder compound, ...	2	134.6	21600	1.13
Triple....	1	140.0	20800	1.15

It will again be evident that although the "coefficients of performance" do not rise so high as in the preceding table, the maximum value is in the same vicinity, or for a ratio of augmented surface to the screw's disk of 127.2. Although I give no more examples, many more could be added all in support of the same general fact.

Now, having shown what actual trial has determined to be the most efficient screw in these particular cases, it might be well to compare it with such a propeller as would result from the use of the rules given in the paper.

I shall select two examples from the first series, viz., those numbered 4 and 15.

Number.	I. H. P.	Diameter, Feet.	Pitch Diameter.	Speed, Knots.	Revolutions.	Length, Feet.	Vessel's Prismatic Coefficient.	$\frac{\text{Speed, Knots}}{\sqrt{\text{Length, Feet}}}$	$\frac{\text{Augmented Surface} \times V^3}{\text{I. H. P.}}$
4	893	15.00	1.265	10.25	61	270	.760	.624	20100
15	1060	15.58	1.254	10.13	60.7	285	.800	.600	24900

It is fairly certain that the wake of these two vessels is not less than 25%, and in comparing the calculated with the tabular coefficients we shall assume that the pitch ratio is in each case 1.25, which will be sufficiently near for the purpose.

The multiplier for wake by table III is .85.

CALCULATION TO DETERMINE EFFICIENCY.

No. 4. Speed modified for wake 10.25 × .85 = 8.72;

$$C_a = \frac{\text{Area} \times 8.72^3}{\text{I. H. P.}} = \frac{176 \times 8.72^3}{893} = 130.8.$$

By inspection of the table this is equivalent to an efficiency of 67%.

No. 15. Speed modified for wake 10.13 × .85 = 8.63;

$$C_a = \frac{\text{Area} \times 8.63^3}{\text{I. H. P.}} = \frac{190 \times 8.63^3}{1060} = {}_1 15,$$

or equivalent to an efficiency of about 63.5%.

By interpolating for the values of C_r the revolutions of the two work out by the tables to 59.9 against 61 for No. 4 and 59.8 against 60.7 for No. 15, which indicates a slightly excessive wake having been assumed; but the variation is not great enough to upset the calculation as an illustration of the incorrectness of the author's assumption.

Thus by comparsion with table II the propeller of No. 4 might be expected to be $100\left(\frac{67}{63} - 1\right) = 6.2$ per cent more efficient than No. 15, while actual trial shows No. 15 to have been propelled 24% more efficiently than No. 4.

But let it be looked at in another way. Let the calculation be made to determine the diameter of the most efficient propeller for No. 16.

In order to keep the dimensions as small as possible let the right-hand value of C_a for 69% efficiency, viz., 217, be taken.

Then area of disk, $\frac{C_a \times \text{I.H.P.}}{\text{Speed}^3} = \frac{217 \times 1060}{8.63^3} = 358$, or equivalent to a diameter of 21.3 feet. The draught of the vessel being sufficient, this is quite an admissible diameter. The ratio of augmented surface to screw's disk would in this case be 68.5, and we know that if the efficiency curve be drawn through the values of

$\frac{\text{Augmented surface} \times V^3}{\text{I. H. P.}}$ for this class of vessel and the power necessary to propel the whole system of ship and screw at 10.13 knots per hour be calculated by the use of the coefficient thus obtained from experiment, it would be not far short of 1500 horses, or with an efficiency of about 70% of that whose conditions by the table should be 8% less.

These views and calculations are not based entirely on the series of examples given in the tables, but have been confirmed by the application of the same method of analysis to over two hundred trials.

In the case of the fine-lined ships, the proportions which would be worked out by use of the constants in table III give results much more nearly corresponding with maximum efficiency of propulsion provided the coefficients on the right-hand side of the crown of the curve over table II be selected; but if those on the left-hand side be chosen, the divergence will be found considerable. If, for example, those under 67% to the left be chosen against those next under 69% and the vessel be a single-screw vessel of average form and such as is referred to in the diagram accompanying this paper, with a prismatic coefficient of about .65, an analysis of trials would lead me to expect a 10 per cent loss of efficiency against $3\frac{1}{2}$% of the table published in the paper.

These conclusions are based on a method of analyzing the trials of vessels to which I have already referred, and which consists of a comparison of the powers relatively to size and speed of similar vessels at approximately corresponding speeds with the ratio of their augmented or wetted surfaces to a propeller of standard pitch and surface ratio but calculated to give the same I. H. P., under similar conditions, as that with which each is fitted.

The values of the "coefficients of propulsion" are plotted down as ordinates upon the ratios of the surfaces to the disk areas of the propellers as abscissæ and a curve drawn through the points.

The figure illustrates the method as applied to the trials of a series of fine-lined vessels and for speeds of .75 $\sqrt{L}$. The propeller of 1.25 pitch-ratio which gives the maximum propulsive coefficient is evidently that whose disk area is about $\frac{1}{38}$ of the augmented surface. The rapid fall of the curve towards the left side with increase of diameter is the reason why I advise the adoption of the coefficients on the right-hand side of the maximum values on Table II if it should be used.

It is stated that fine-pitched screws give the best results with full ships. This is rather a vague statement, as some may consider

a pitch-ratio of 1.2 as fine, while others would not speak of the screw as specially finely pitched unless its ratio were under 1.0. If the author is of the latter class, I am under the impression that his statement is subject to grave question, provided he prefers the fine pitch-ratio for the purpose of securing high mechanical efficiency; but, on the contrary, am inclined to state as my experience, after having carefully examined the trial data of some hundreds of full-lined cargo-vessels, that fine pitches are somewhat inferior in efficiency.

When on the subject of negative slip, of which the writer has given a very fair account, I think he has omitted to name a very frequent source of apparent negative slip, viz., an incorrect assumption of the propeller's true working pitch.

This may be due to several causes:

(1) The screw may have twisted in casting, and may not have been measured afterwards;

(2) The pitch may be variable, and the estimated mean pitch may be incorrect;

(3) The sections of the blades may be of such a form as to increase the effective working pitch; and,

(4) All propeller-blades spring in working, so that they assume a pitch different from, i.e., generally greater than, that at which they are set in the workshop.

In regard to (1): This used formerly to be a frequent source of incorrect conclusions, but as it is a very common custom to "pitch" all propellers when in the workshop, error is less likely to arise from this cause.

(2) is more likely to give rise to trouble, as it is no uncommon thing to find blades twist in casting, and it is usual to take the measurements of the pitches at equal distances from the tip to the root, and to take the arithmetical mean as the pitch. If this is done and the blade is coarsest at the circumference, then it is highly probable that the "mean pitch" will be considerably less than the effective mean pitch, the result of which is to diminish the apparent slip.

(3) is a factor, but one not likely to enter much into the question with ordinary forms and slip-ratios.

But (4) is most important. Although with cast-iron and cast-steel screws as usually proportioned the spring of the blades when at work appears to be so slight as not to be worth consideration, the blades of the majority of bronze screws spring much in working, and judging by the decrease of the number of revolutions for the same speed and conditions of trim in vessels whose steel or cast-iron

blades have been replaced by similar bronze blades, but of lighter section, the effect of this springing of the blades has been in some cases to augment the working pitch as much as 10%, but generally it is about 7%.

That the effect of the blade springing is to augment the pitch, needs better reasoning to show; but it has been placed upon a still surer basis, i.e., actual experiment, by the loading of a blade.

Now, such information as I possess relative to the screws of our naval ships in which negative slip has been recorded would lead me to submit this as a sufficient explanation of a very large proportion of the cases of recorded apparent negative slip in the British Navy.

That our naval engineers recognize the effects (2) and (4) will be seen by a quotation from the preface to the Admiralty Blue Book, "Trials in H. M. Screwships and Vessels, 1882:" "With regard, however, to the calculated slip of various screws, it must be borne in mind that there is a difficulty in ascertaining with certainty the effective mean pitch when the pitches of various parts differ considerably, and that the mean pitch, when a screw is in action, is liable to be altered by the pressure of the water; the amount of slip, therefore, as printed in the table may in some cases be incorrect," etc.

In the important matter of engines' modulus of delivery the author assumes the very modest figure of .77 as a basis for his calculations. This may be correct for some classes of engines, but for a modern marine engine of good design and workmanship it is too low. About .83 is much nearer the mark, and even this is frequently exceeded.

It is somewhat difficult to understand the meaning intended to be conveyed when it is stated that three-bladed screws are preferred for high speeds. It is true that in vessels which are intended for high speeds, such as cruisers, etc., the propellers are frequently of small size, so that constructional reasons recommend their being made with three blades; they are also somewhat less costly than four-bladed screws.

These are the grounds which in my experience generally determine to their adoption—not any supposed superiority in efficiency over screws with four blades.

The figures accepted after Mr. R. E. Froude for the relative thrusts of four, three, and two bladed screws of the same diameter, and with blades of equal dimensions of form and working under the same conditions of advance and slip, are 1.0, .865, and .65.

It is but right that the fact that these ratios of effect are true

only for one pitch-ratio should be pointed out. Very little reasoning will show that they should approach equality by indefinite reduction, and the values of 1.0, .75, and .5 by indefinite increase of pitch-ratio; and there is certainly sufficient variation within the limits of pitch-ratio included in the author's tables to warrant some more definite information being tendered if it exists. As a matter of fact, the figures are only correct in the case of the particular type of screw with which Mr. Froude's experiments were made for a pitch-ratio of from between 1.2 to 1.25. They should be about 1.0, .90, and .72 for .8 pitch-ratio, and 1.0, .79, and .58 for 2.0 pitch-ratio.

I might also suggest that the figures in Table III are somewhat incorrect. For example, the multiplier for the speed with 30% of wake is given as 0.8. Now I take it that a factor has already been included in the constants of Table II which has practically reduced the vessel's speed to 90% of its actual value for the assumed wake of 10%, and therefore for a modified percentage of wake the speed should be calculated thus:

$$\frac{\text{Speed of ship}}{0.9} \times (1-\text{wake fraction}).$$

Thus for a wake of 30% it would become

$$\frac{\text{Speed of ship}}{0.9} \times (1 - 0.3) = 0.778 \text{ speed},$$

against the 0.8 of the table; making a difference of 2.9% in the speed and about 8.9 in the constant for the Table III calculated therefrom.

MR. SYDNEY W. BARNABY (reply in writing after the meeting): —Mr. Kafer states that a propeller designed for a particular vessel in accordance with my advice did not absorb half the power he expected when running at the full number of revolutions. As I have never been in communication with Mr. Kafer, I presume he refers to some rules in my book on "Marine Propellers." It appears from his remarks that the propeller he selected as a model was driving a vessel very different in form from that for which a screw was required. I have always drawn attention to the necessity for the exercise of discretion in selecting a vessel whose propeller is to serve as a model. No calculation made upon the basis of the performance of

the propeller of so fine a vessel as the "Cushing" would be of service in the design of a screw for a full vessel of large resistance.

In answer to Col. Stevens I would say that we find the arrangement of screw-turbine described stops the vessel very quickly. Still I should expect it to be somewhat inferior in this respect to the arrangement adopted in the "Bergen," because the bow-screw would be less, both in diameter and pitch, than that of the "Bergen." The thing to consider would be whether a slight inferiority in stopping power would not be more than compensated for by the economy in power which would be realized when under way.

In reply to Mr. Howden I can only say that it would be hopeless for me here to attempt to convince him. He has, as he says, been urging his views for many years. In 1890 he read a paper before the Institute of Naval Architects in London, in which he stated that he took exception to almost all the leading ideas on which Rankine, W. Froude, R. E. Froude, Cotterill, Blechynden, Greenhill, and others formulated their theories of the screw's action.

His arguments were, to my mind, completely disposed of on that occasion by Mr. R. E. Froude, but he remains unconvinced. I am content to be on the side of the majority, and say with Newman, "*Securus judicat orbis terrarum.*"

I cannot follow Mr. Howden into a discussion of my own 1890 paper before the London Institution of Civil Engineers. Any one reading that will see that while Mr. Howden describes correctly enough, so far as he goes, the method employed by both Mr. Froude and Mr. Thornycroft in their model experiments, he unintentionally misrepresents the reasoning by which certain conclusions were arrived at. I take exception also to the statement that I have come to the conclusion that a propeller that makes little slip is a very bad propeller and of low efficiency. "Little slip" is a comparative term, and what some would consider little others might consider much. Table I gives the slip for highest efficiency for screws of different proportions, and the apparent slip with a 10 per cent wake is, in the case of the finest pitch-ratio, as low as 5½ per cent. I call this a little slip; perhaps Mr. Howden does not! Yet at this slip the best effect will be obtained with that ratio of pitch to diameter. The speed of advance through the water at which the model screw is made to give zero slip and zero thrust may be anything you like. Four and a half knots was chosen as a convenient speed by Mr. Thornycroft, but any other speed would not have altered the results obtained. Mr. Howden is wrong in saying that

the efficiency was supposed to be proportional to the thrust exerted by the model. After a certain thrust is reached the efficiency becomes less as the thrust and slip are increased. The efficiency was measured by the ratio which the thrust horse-power given out by the model (that is, the thrust multiplied by the velocity) bears to the power expended in driving it. The correctness of this method does not admit of doubt. Mr. Howden's way of drawing geometrically the motion of the water while in contact with the screw-blade is that usually employed, but his assumption that it represents the whole motion given to the water cannot be accepted. Mr. Froude went fully into this matter in his remarks on Mr. Howden's paper already referred to, when the same diagram was produced. He showed that the motion of the water must be continued after passing the screw-blade until it was gradually destroyed by friction with the surrounding fluid. I dissent entirely from the statement that the motion of a screw-blade through water is analogous to that of a half model of a ship propelled in a continuous straight course with the flat side lying slightly at an angle.

In the first place, a screw-blade works wholly submerged, and is therefore in a different condition from a ship travelling at the surface which can dissipate the displaced water by means of surface waves; and secondly, a screw produces a rotary movement in the water, which a ship does not. It is this rotary motion which causes loss of pressure in advance of the blades, and a consequent flow of water towards them.

Mr. Blechynden finds fault with the assumption that "to insure maximum mechanical efficiency of propulsion it is necessary to select a screw of such proportions as will work with the power required for propulsion at that slip-ratio which has been found by the trials of small model screws in still water to correspond with maximum efficiency." I have here followed exactly the method adopted by Mr. Froude in his paper of 1886 on "The Determination of the Dimensions of Screws." In that paper Mr. Froude selected the 9 abscissa value corresponding to about the summit of the curve of efficiency in Table II as being that to be preferred. I believe that for ships of moderate proportions the sizes of screws obtained by using the constants in this column are those which will give the best mechanical result. The examples which Mr. Blechynden gives are all chosen from one class of vessels, having very full lines.

It is conceivable that such vessels, having a prismatic coefficient of between .7 and .8, may require special treatment. He is a better judge than I as to the best proportions of propellers to drive them;

will depend upon the length of the ship, the form of the lines, the state of the bottom, and the position of the propeller.

Let us assume that it is 10% of the speed of the vessel; in other words, that the velocity of feed is 10% less than the ship's speed.

Again, the indicated horse-power of the engines will exceed that transmitted to the screw by an amount equal to the power expended in internal friction. This ratio may be taken as I.H.P. : power in shaft :: 100 : 77.

Finally, taking the mean efficiency of the propeller at 65 per cent we have all the elements necessary to enable us to fix the dimensions of a screw to work behind a ship at the real slip suitable to its pitch-ratio.

Now, thrust horse-power or T.H.P. = thrust of screw $\times$ velocity of feed.

Effective horse-power or E.H.P. = tow-rope resistance $\times$ speed of ship.

If we agree to assume tow-rope resistance = thrust $\times$ .9, and velocity of feed = speed of ship $\times$ .9, then T.H.P. = E.H.P.

Since I.H.P. is greater than E.H.P. by the amount wasted by the friction of the engine and by the screw, using the assumed values of these losses, we get

$$\text{E.H.P.} = \text{I.H.P.} \times .77 \times .65;$$

$$\therefore \frac{\text{E.H.P.}}{\text{I.H.P.}} = .5 = \text{propulsive coefficient.}$$

These assumptions were made by Mr. R. E. Froude, in his paper of 1886,* from which the above has been condensed, and I have adopted them in constructing the constants in Table II.

The values of C_A and C_R in that table are obtained from the model trial results at any slip-ratio as follows:

Let thrust of screw in pounds.............. $= T$;
velocity of feed in knots per hour........ $= v$;
speed of ship $\left(= v \times \frac{1}{.9}\right)$.............. $= V$;
revolutions per minute.................. $= R$;
disk area of model in square feet......... $= A$;
diameter of model in feet............... $= D$;
$\frac{Tv}{33000} \times 2 \times 101$......................... = I.H.P.

* Trans. Inst. Naval Architects, XXVII, p. 250.

Then

$$C_A = \frac{A \times V^3}{\text{I.H.P.}};$$

$$C_R = \frac{R \times D}{V}.$$

Allowance can be made for different values of wake percentage by multiplying the speed of ship V by the corresponding wake factor given in Table III.

A correction can also be made for any deviation from the assumed value of propulsive coefficient. If, for example, it is desired to take this at .6 instead of .5, the I.H.P. must be multiplied by the ratio $\frac{.6}{.5}$.

Again, the constants are suitable for four-bladed screws; they can be used for three-bladed or two-bladed screws by multiplying the I.H.P. by $\frac{1}{.865}$ or $\frac{1}{.65}$, respectively.

EXAMPLES IN THE USE OF TABLES.

Example 1.—Find the diameter and revolutions of a screw to work at maximum efficiency for a vessel of 20 knots speed and 6000 I.H.P., pitch-ratio to be 1.2.

The disk area constant (C_A) in the table for this pitch-ratio is 288.

The revolutions constant (C_R) in the table for this pitch-ratio is 92.

$$\text{Disk area} = C_A \times \frac{\text{I.H.P.}}{(\text{speed in knots})^3} = 288 \times \frac{6000}{20^3} = 216 \text{ sq. ft.}$$

$$\therefore \text{ Diameter} = 16.5 \text{ feet. Four blades.}$$

$$\text{Revolutions} = C_R \times \frac{\text{speed in knots}}{\text{diameter in feet}} = 92 \times \frac{20}{16.5} = 111.$$

Example 2.—Find the pitch and revolutions of a screw to work at maximum efficiency for a vessel of 20 knots speed and 6000 I.H.P. Diameter not to exceed 15.5 feet. To have four blades. Disk area = 189 sq. ft.

$$C_A = 189 \times \frac{20^3}{6000} = 252.$$

Wake Percentage	Multiplier for Wake Correction.	Wake Percentage.	Multiplier for Wake Correction.	Wake Percentage	Multiplier for Wake Correction.
0	$\frac{1}{.90}$	7	$\frac{1}{.97}$	18	.910
1	$\frac{1}{.91}$	8	$\frac{1}{.98}$	19	.900
2	$\frac{1}{.92}$	9	$\frac{1}{.99}$	20	.888
3	$\frac{1}{.93}$	10	1.0	21	.876
4	$\frac{1}{.94}$	11	.989	22	.865
5	$\frac{1}{.95}$	12	.977	23	.855
6	$\frac{1}{.96}$	13	.965	24	.844
		14	.955	25	.832
		15	.943	26	.821
		16	.932	27	.810
		17	.921	28	.800
				29	.788
				30	.778

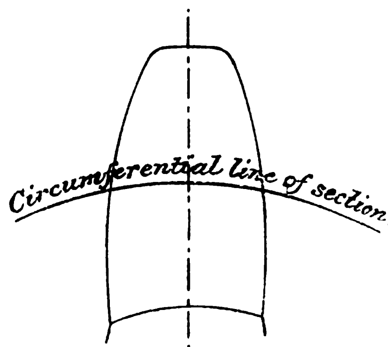


Fig. 2.

Fig. 3.

Ship passing through water in a
t with its flat side at a slight
represents the actual continuous
peller blade through the water
0 per cent slip.

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naby's sketch, his ferry-boat would have to reverse ends every trip, or sacrifice backing power in one direction.

MR. HOWDEN:—I would like to say a few words on this subject, having studied it considerably, but on account of Mr. Barnaby not being present, and the fact that my conclusions on the subject are entirely opposed to his, I have some hesitation in stating such directly opposed views in his absence, as I feel as if it were taking him at a disadvantage. Having, however, come several thousand miles to attend the Congress, I can scarcely allow this discussion to pass without saying a word or two.

Mr. Barnaby says in the last two paragraphs of the first page: "It is now established that for every different ratio of pitch to diameter there is a particular slip-ratio at which, and at which only, maximum efficiency can be obtained." "Thus it has been ascertained experimentally, that in the case of a screw of a particular standard form, the real slip, as measured by pitch multiplied by revolutions, at different pitch-ratios should be of the amount given in Table I in order to obtain the best results." I must entirely dissent from these conclusions, and that it is established that these things are as there stated, because the table on which these conclusions are based has been got up from experiments that could give no proper indication of the actual work of a screw in propelling. In the second page Mr. Barnaby describes the kind of experiments from which the table was got up. He says: "It may be interesting to describe the means by which these important results have been reached. They were foreshadowed in 1878 by the late Mr. Froude, who has deduced by theory curves of thrust, horse-power, and efficiency similar to those afterwards obtained by experiment."

Mr. Barnaby then goes on to describe the method adopted by Mr. Froude and Mr. Thornycroft to ascertain the thrust, horse-power, and efficiency of propellers. This was done by revolving a small screw on a shaft in the bow of a steam launch which was at the same time driven by an independent screw in the stern of the vessel in the usual manner, the bow-screw acting merely on a dynamometer. I may use this sketch of a boat already drawn on the blackboard to illustrate how the propellers were placed. [Sketch made showed a launch with a screw in the stern in the usual manner, and at the other end a small screw below water-line, carried clear of the bow, with its shaft entering the boat.] The propeller in the stern drove the boat, and was regulated to give a uniform speed of 4½ knots. The small propeller in the bow, from the performances of which this table was formed, was only 9